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Schulz and Marble

Investigation of  
Induction Machines

Electrical Engineering  
E. E.

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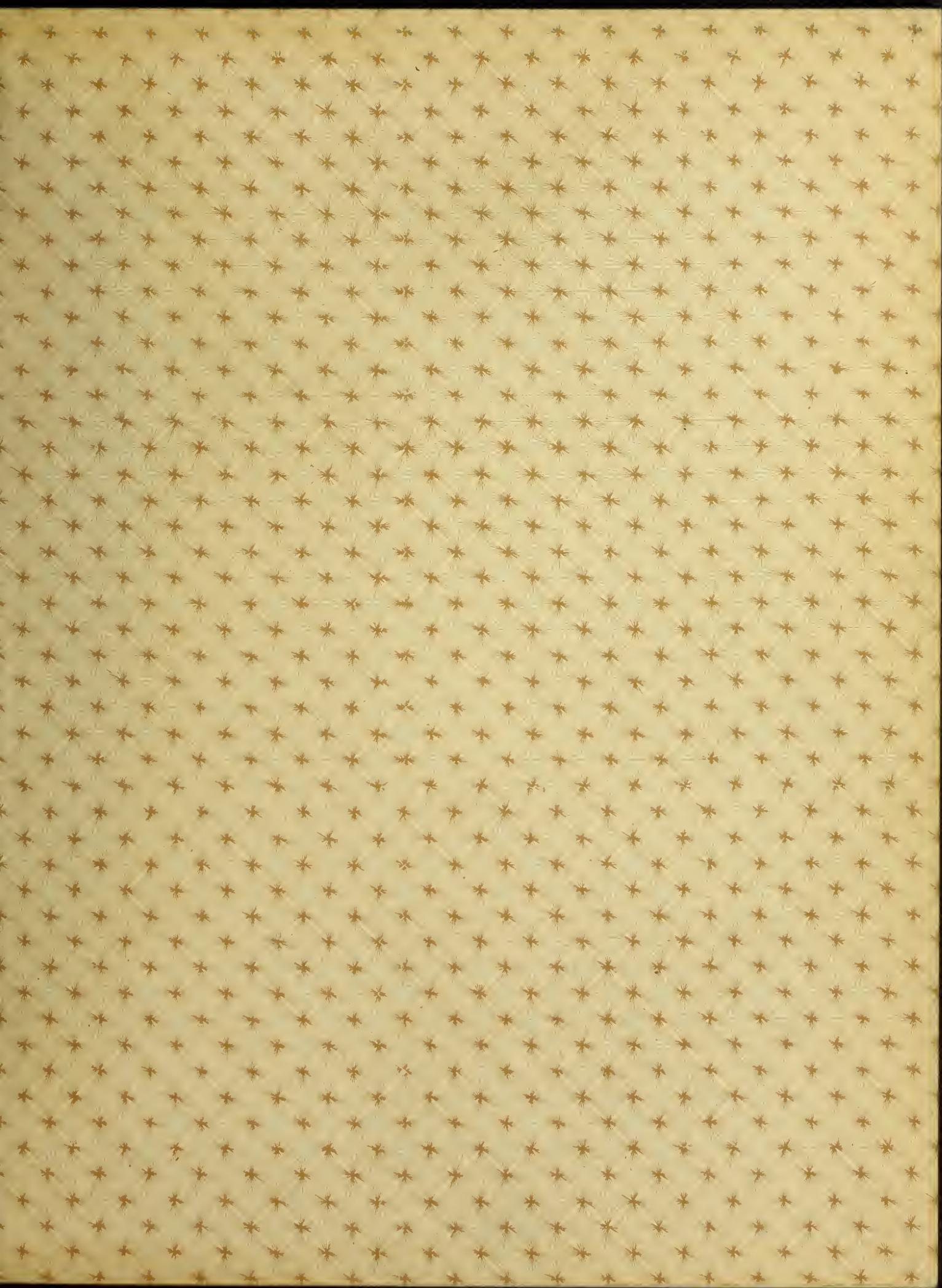
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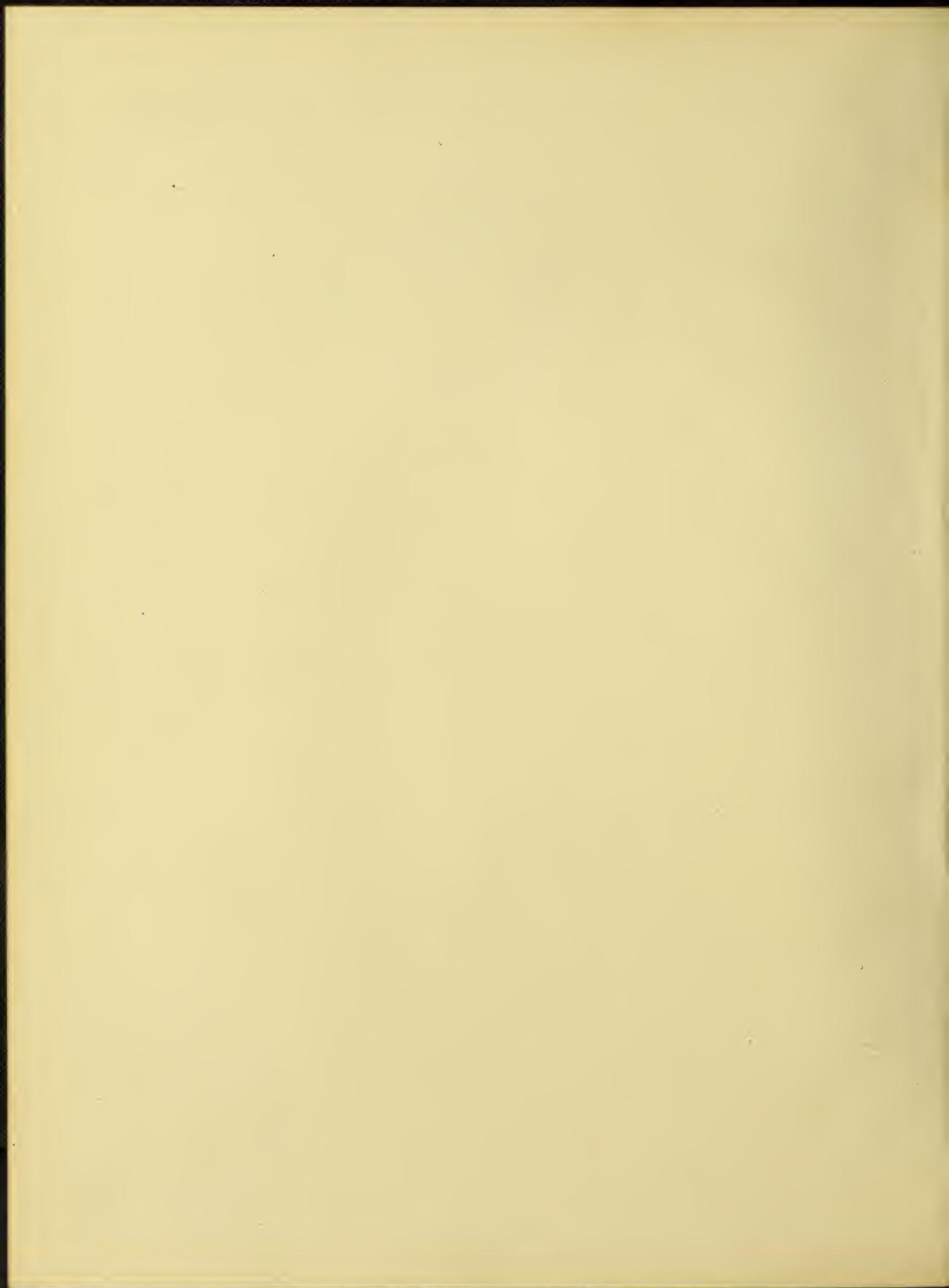
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THEORETICAL AND EXPERIMENTAL  
INVESTIGATION OF INDUCTION  
MACHINES

BY

WILLIAM FREDERICK SCHULZ,

DIPLOMA IN ELECTRICAL ENGINEERING (JOHNS HOPKINS UNIVERSITY), '93

AND

HARRY CURTISS MARBLE, B.S., '96

THESIS

FOR THE DEGREE OF ELECTRICAL ENGINEER

IN THE GRADUATE SCHOOL

UNIVERSITY OF ILLINOIS  
1900



UNIVERSITY OF ILLINOIS

June 1, 1900

Bind. 17 Q22 M91.2  
THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

William Frederick Schulz and Harry Curtiss Marble

ENTITLED Theoretical and Experimental Investigation of Induction

Machines -

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Electrical Engineer

Wm. S. Aldrich

HEAD OF DEPARTMENT OF Electrical Engineering

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## P R E F A C E.

The work on this thesis was undertaken with the collaboration of Mr. Harry C. Marble, B.S., Assistant in Electrical Engineering, and a post graduate student in the Department of Electrical Engineering of this university.

In treating the theory of induction motors, the method developed in the well known book on "Alternating Current Phenomena" by Mr. Chas. P. Steinmetz, has been followed.

Through the courtesy of the Wagner Electric Manufacturing Company, of St Louis, Mo., we were supplied with a 4 h.p. and a  $7 \frac{1}{2}$  h.p. motor on a special loan to the University of Illinois, for this investigation. Also, we visited the works of this Company May 17th and 18th, and there made a regular factory test of a 10 h. p. motor, using their methods and the University of Illinois instruments connected up with the regular shop testing instruments of this company.



## T A B L E   O F   C O N T E N T S.

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" 111	" " 7- $\frac{1}{2}$ " " " " " 32	

## EXHIBIT 10. 6. 2. 2. 2. 2.

ITEM	DESCRIPTION	EXPLANATION
1	Initial budget for 1967 was off	Initial
2	by 100,000,000	initial budget
3	1967 budget is 1000	1967 budget
4	1000,000,000	1000,000,000
5	Initial budget	Initial budget
6	Initial budget	Initial budget
7	Initial budget	Initial budget
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10	Initial budget	Initial budget

## EXHIBIT 10. 7. 4. 2. 2. 2. 2. 2.

ITEM	DESCRIPTION	EXPLANATION
1	Initial budget	Initial
2	Initial budget	Initial
3	Initial budget	Initial
4	Initial budget	Initial
5	Initial budget	Initial

## EXHIBIT 10.

ITEM	DESCRIPTION	EXPLANATION
1	Initial budget	Initial
2	Initial budget	Initial

PLATE	IV	Eff & Idle Watts, True Watt Input Base	Page
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"	IX	Eff & idle watts on $\frac{1}{2}$ load base	39
"	X	Eff & Idle Watts on ture Watt Input Base for Motors at 104 Volts	40
"	X	All curves 10 H.P. at 208 Volts	41



THEORETICAL & EXPERIMENTAL  
INVESTIGATION OF  
INDUCTION MACHINES.

In writing this thesis the author has had a twofold purpose in view, as indicated by the title. The object has been to test by brake the output of single phase induction motors, which combined with electrical measurements and the electrical and mechanical data of the machines, determines the true and apparent efficiency, power factor, idle watts, torque, slip, etc. Moreover it was expected that the calculated results from theoretical considerations would afford an interesting comparison with those experimentally determined, but owing to the difficulties encountered in determining the proper values of the reactances of rotor and stator and the magnetic flux, these calculations could not be made.

Before discussing the experimental results it may not be out of place to explain the principle of an induction motor, such as one of the short-circuited-armature type.

The stator or fixed part consists of an annular field of laminated iron having wire coils wound in slots and arranged to form as many poles as it is desired the machine should have. The rotor or rotating part consists of a cylinder of laminated



consists of a cylinder of laminated iron, mounted on a shaft, having also slots in which are imbedded either wire coils or copper bars, all of which are short-circuited on themselves by a copper or brass ring, or other device.

The alternating current is supplied to the stator, establishing in it a rotary field of force. This field is cut by the conductors of the rotor, inducing in them an E. M. F. which though small is sufficient to set up a large current in the rotor winding. The reaction of the field of force induced in the rotor, on the rotary field of the stator causes the rotor of the single phase machine to continue to revolve if once set in motion.

The frequency of the stator rotary field is equal to the frequency of the impressed E. M. F. The revolutions per second of the rotary field are equal to the E. M. F. divided by the number of pairs of poles of the stator. The frequency of the rotor current is the same as this when the rotor is at standstill, but decreases as the rotor speed increases becoming zero at synchronism. Hence the frequency of the rotor E. M. F. varies directly with the slip, and the number of revolutions at any slip is

$$(1-S) N$$

where  $N$  = frequency of stator

$S$  = percentage slip

$SN$  = frequency of rotor.



The stator and rotor are sometimes referred to as the primary and secondary of the motor since they bear to each other the same relation as these parts of a transformer having one of its circuits movable. When the rotor is at standstill it is considered as a short-circuited transformer secondary.

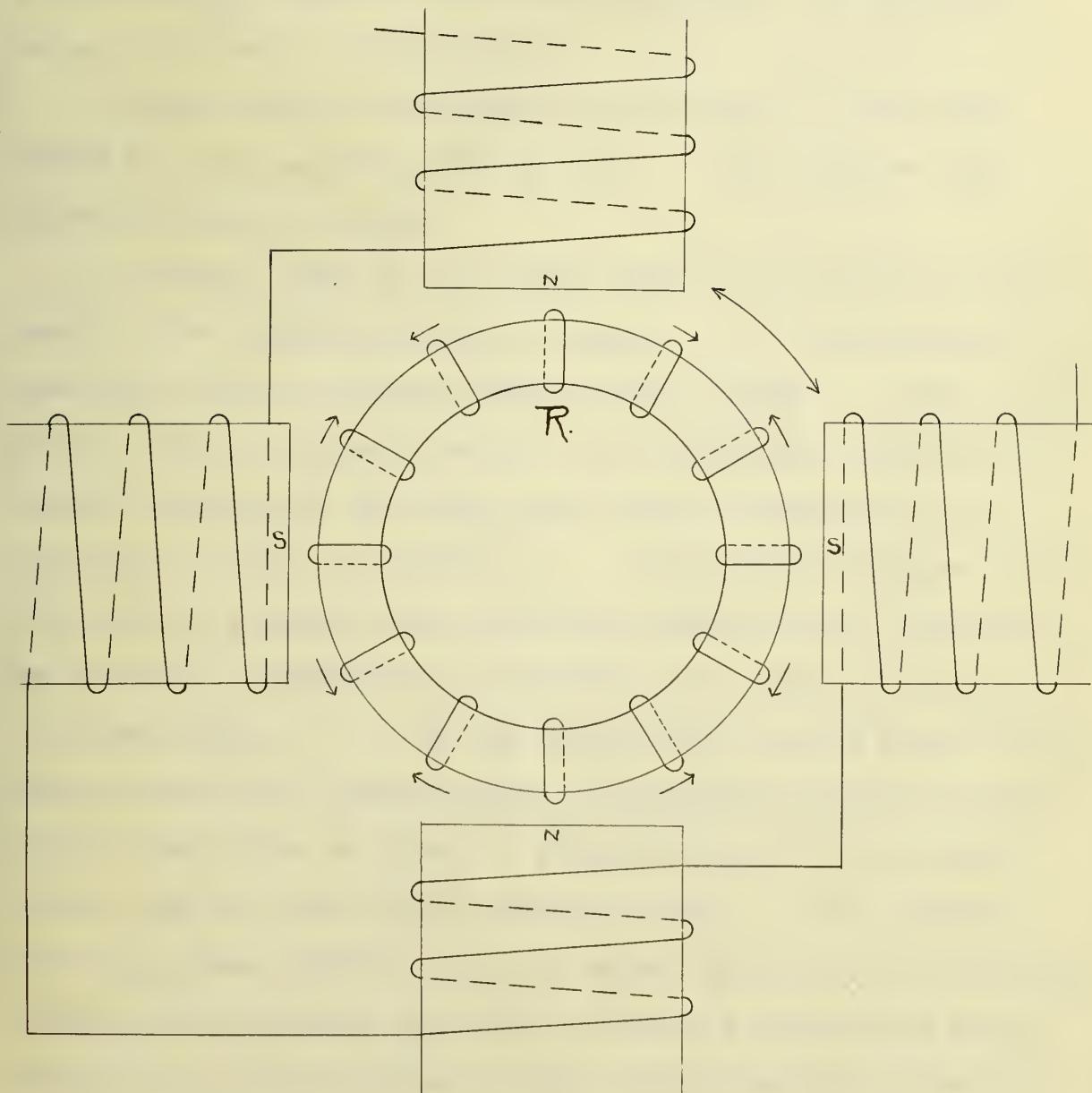
In polyphase induction motors the field produced by the stator windings is rotating, and the rotor will start of itself. In the single phase motor the field is not a true rotating field until the rotor has gotten up to considerable speed, when the resultant of its field and the field of the stator becomes a true rotating field or approximately so in effect, and the motor will therefore keep in motion.

If the rotor is at standstill and is wound with uniformly spaced short circuited coils or bars, the repulsive thrust between induced current and inducing magnetism, in the different coils, will balance each other and there will be no tendency for the rotor to revolve, as is shown in diagram Fig. 1. Here for each coil receiving a rotary thrust in one direction, there is a symmetrically placed coil on the opposite side of the rotor R, receiving an equal thrust in the opposite direction.

To overcome this effect several means are employed, one of these being the "phase splitting" method which consists of a field winding similar to that of a two phase machine. One of the coils contains an inductance, and the other a different inductance or a capacity.



— Fig. 1. —





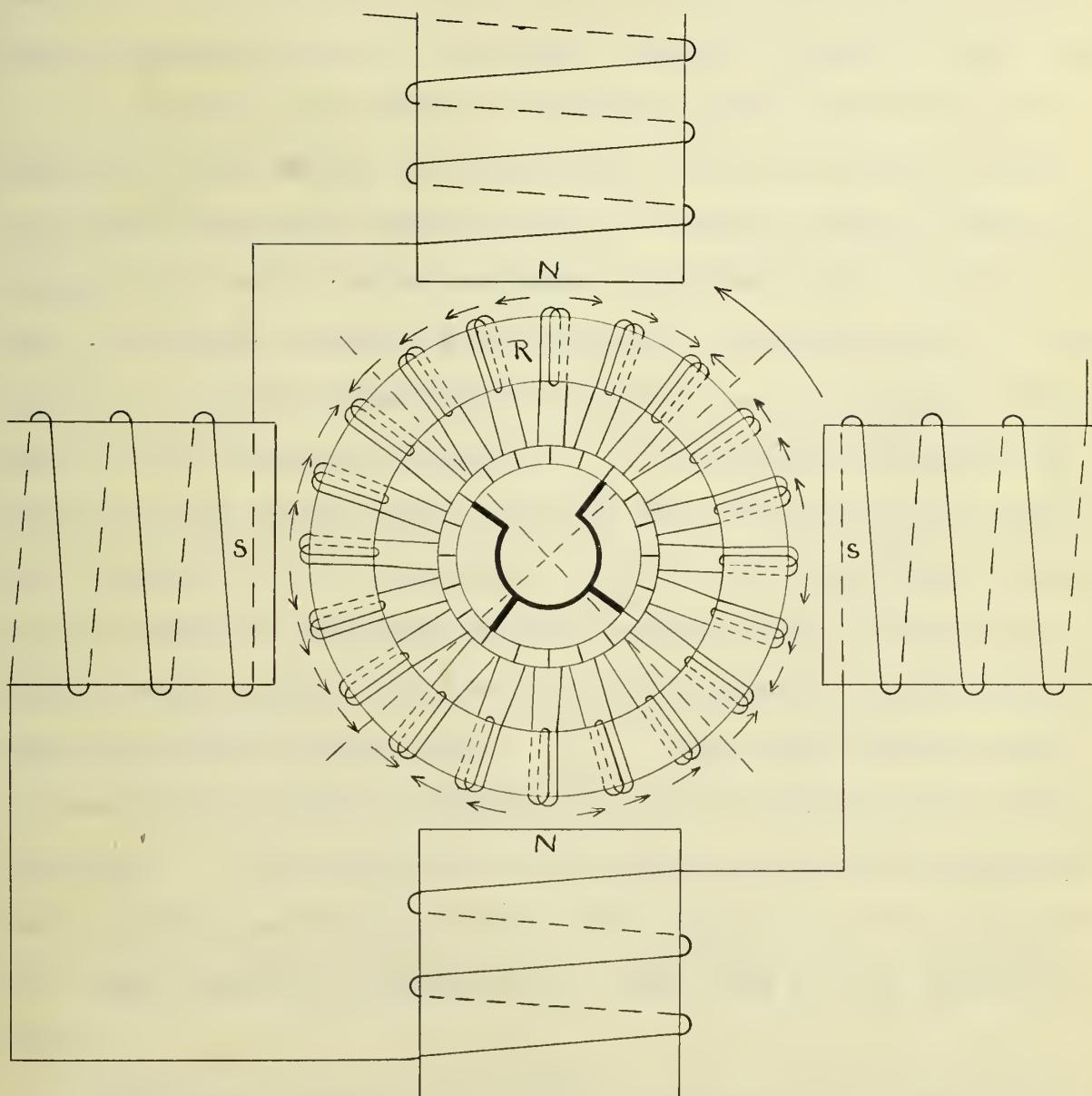
Both coils are connected in parallel in starting, thus causing a difference of phase of the field magnetism, the resultant being, in effect, a rotary field.

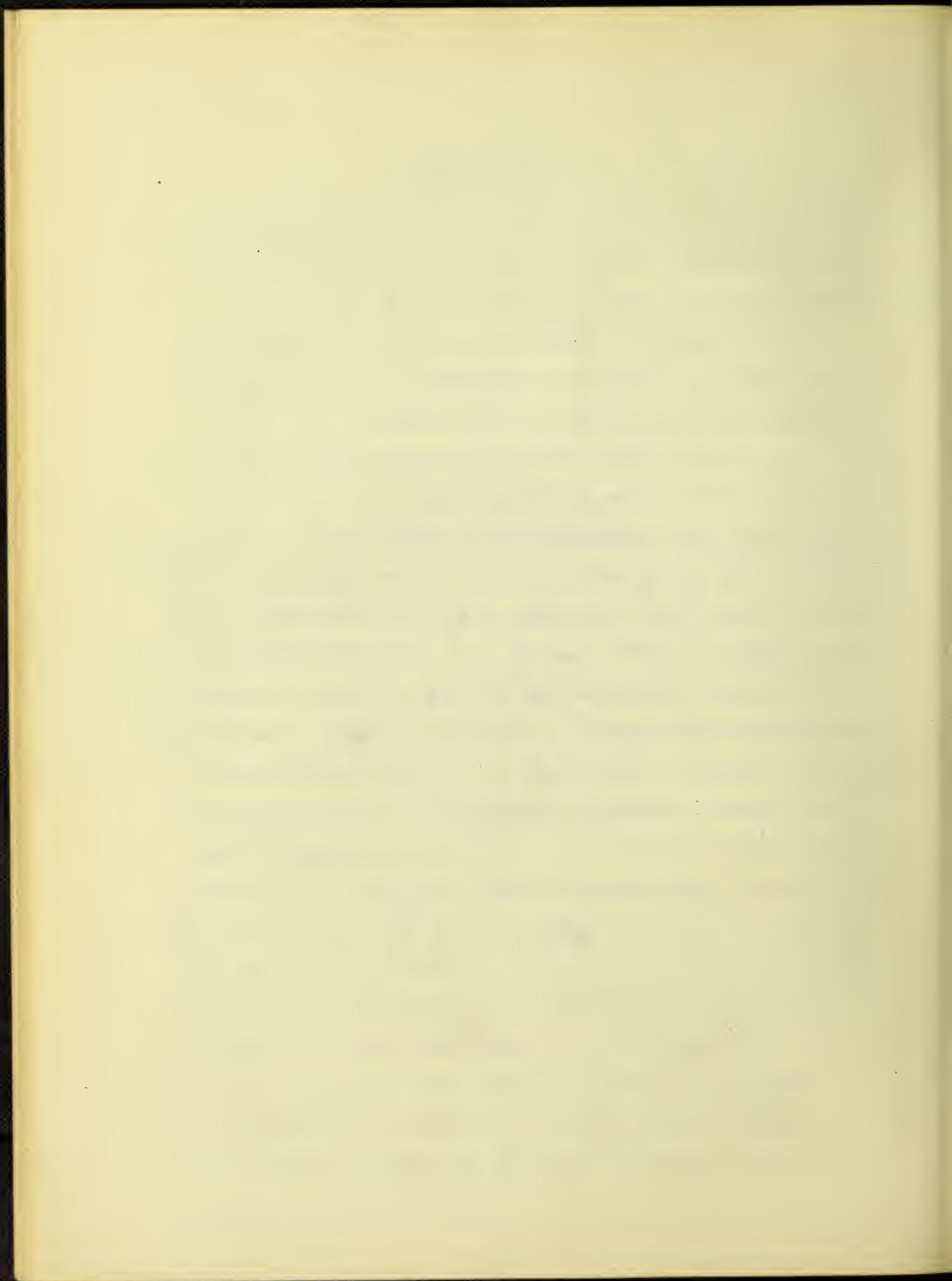
In some motors a commutator is used and the rotor and stator are put in series in starting. The machine then starts as a series motor.

In others, such as the Wagner Motors upon which we experimented, the repulsion method is used. In these motors a commutator having vertical radial bars is used. The winding of the rotor is the same as that of a continuous-wound direct current armature of four pole type, and is connected to the commutator in the same manner. Four carbon brushes, short circuited by a heavy brass connection, bear on this commutator. The armature is therefore equivalent to one having four short circuited coils. If the brushes were placed symmetrically midway between the stator poles, the repulsive thrusts would balance each other as shown in diagram Fig. 1, by the small arrows, and the rotor would remain at rest. If, however, the brushes are shifted from this midway position, the repulsive thrusts are unbalanced as shown in figure 2 (where the small arrows at the circumference of the rotor R show the direction of the repulsive thrust) and the rotor will tend to rotate in the direction in which the brushes were shifted. The speed of rotation increases until it is almost at synchronism, when the brushes are thrown back from the commutator and a ring of



— Fig. 2. —





copper links is forced up against it, thus short circuiting all of the rotor coils. As the field at this speed is approximately a rotary field, the motor now operates just as a polyphase induction motor of the short circuited armature type does.

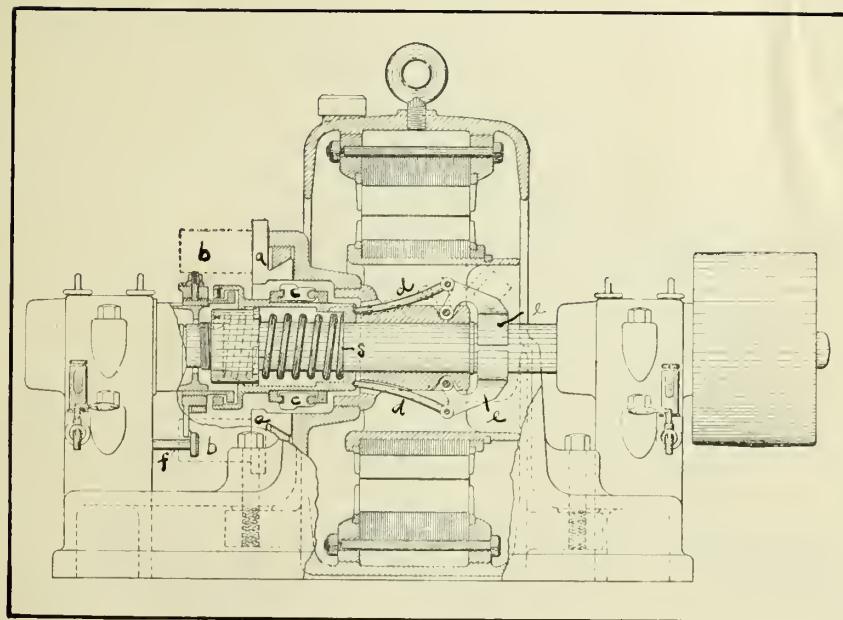
In Fig. 3 is shown a sectional view of the motor, in which (aa) represents the commutator, (bb) the brushes which are short circuited, (cc) the ring of copper links by means of which all the rotor coils are short circuited, (dd) the arms of the centrifugal governor which controls the throwing off of the brushes and short circuiting of the rotor at the proper speed, and (ee) the governor weights. The synchronous speed of the four pole, sixty cycle motor is 1800 revolutions per minute. The governor is set to operate at about 1650 revolutions, allowing the motor to be operated when the frequency is less than sixty cycles, as for instance when the generator speed drops somewhat under a heavy load. When this latter speed is reached the governor weights fly out as shown in the dotted position. By this action the spiral spring (S) is compressed, drawing the brushes back by the spring knob (f) and forcing the copper links (cc) against the inner ends of the commutator bars.

The motors tested were of the standard, two, four, seven and a half, and ten horse-power sizes, respectively.

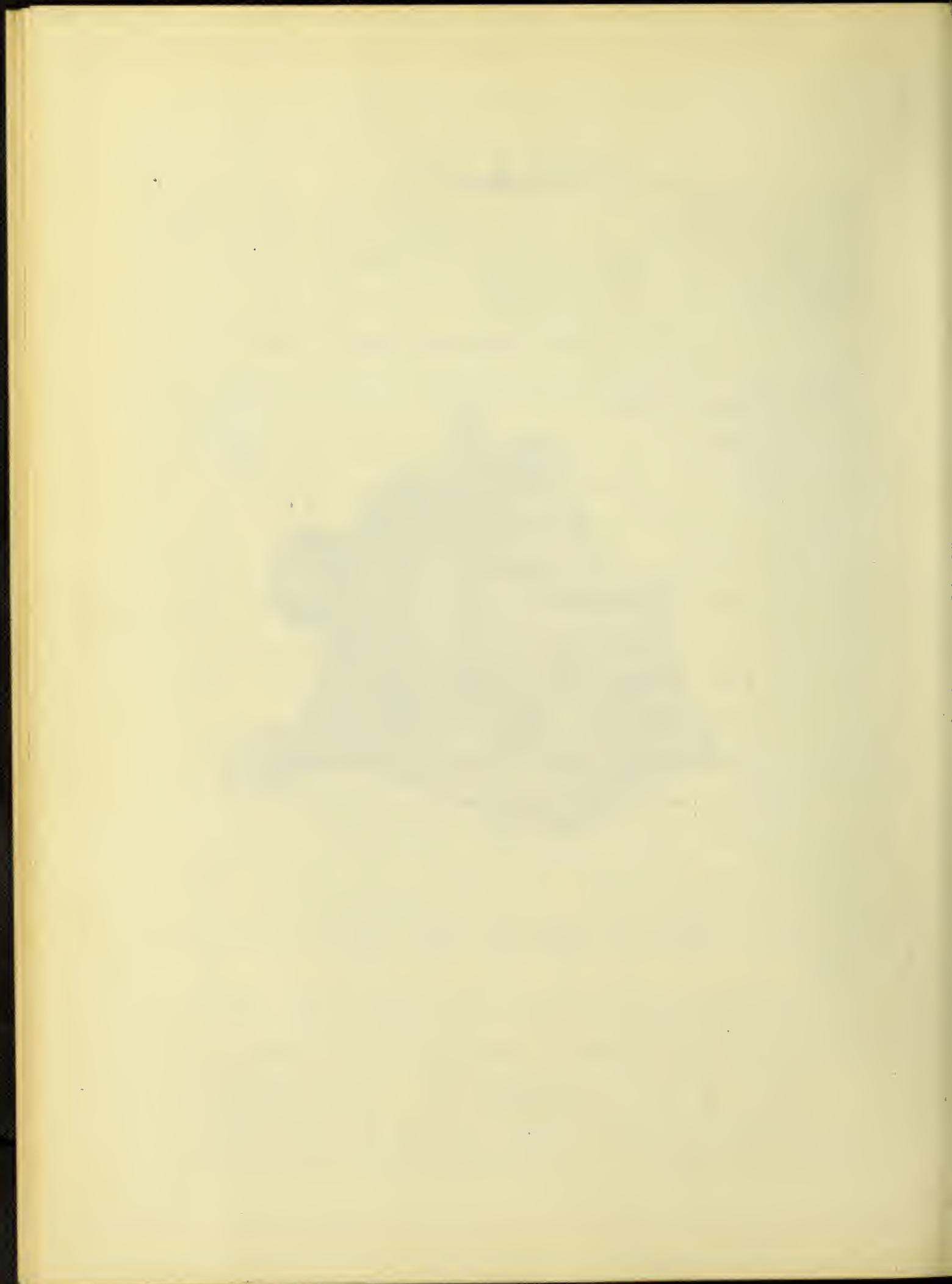
There are four brushes placed  $90^\circ$  apart, except in the two horse-power size, in which there are but two brushes, placed  $90^\circ$  apart. The reason assigned for this is,



— Fig 3. —



Longitudinal Cross Section of Motor.



that larger sizes carrying more current require larger brushes; and that the four brushes mechanically balance to better advantage on the brush carrying ring.

In the blue prints, Figures #4, 5 and 6, are shown sections of the laminae, of which the rotor and stator cores are built up respectively.

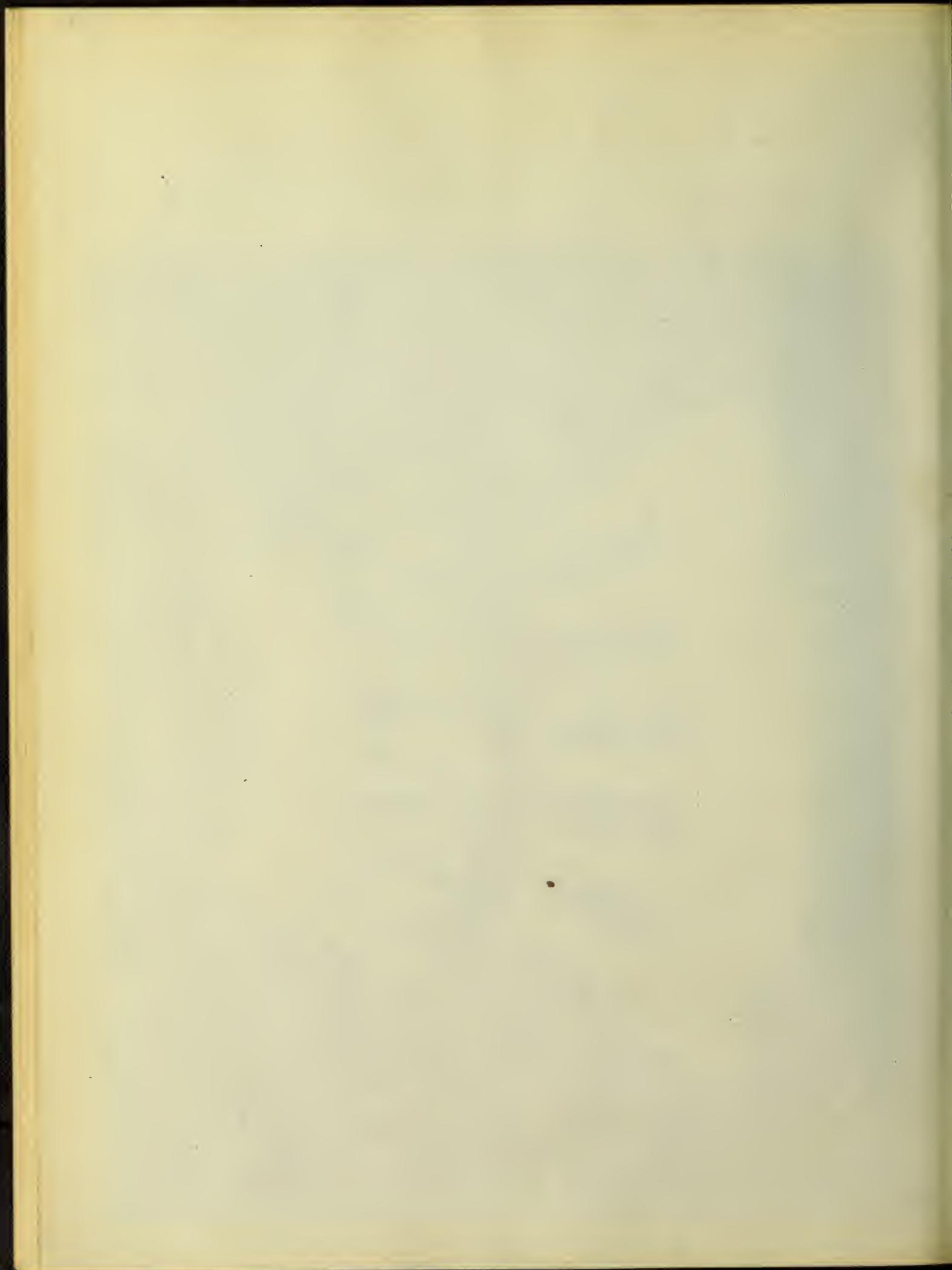
The slots on the rotor are not parallel to the axis of the shaft but are arranged spirally. This brings them into and out of the field of the stator gradually and thus reduces the humming which would otherwise occur. The number of commutator bars is not an even multiple of the number of slots on the rotor. For instance, in the two horse power machine which has a two-circuit, double-layer, drum-wound rotor, there are forty seven slots, but only ninety three commutator bars. In such a winding with a stator having an even number of pairs of poles, there must be an uneven number of coils. There are thus ninety three active coils or 186 conductors. However, in order to wind the rotor symmetrically, with four conductors per slot, the number of conductors should be an even multiple of four. Hence there are  $186 + 2 = 188$  conductors or ninety four coils, and forty-seven slots. The extra coil is left open-circuited, and is used only to balance the armature.

These machines also have a special device for starting under full load or even as much as 75% overload. This is accomplished by bringing out a third terminal forming a



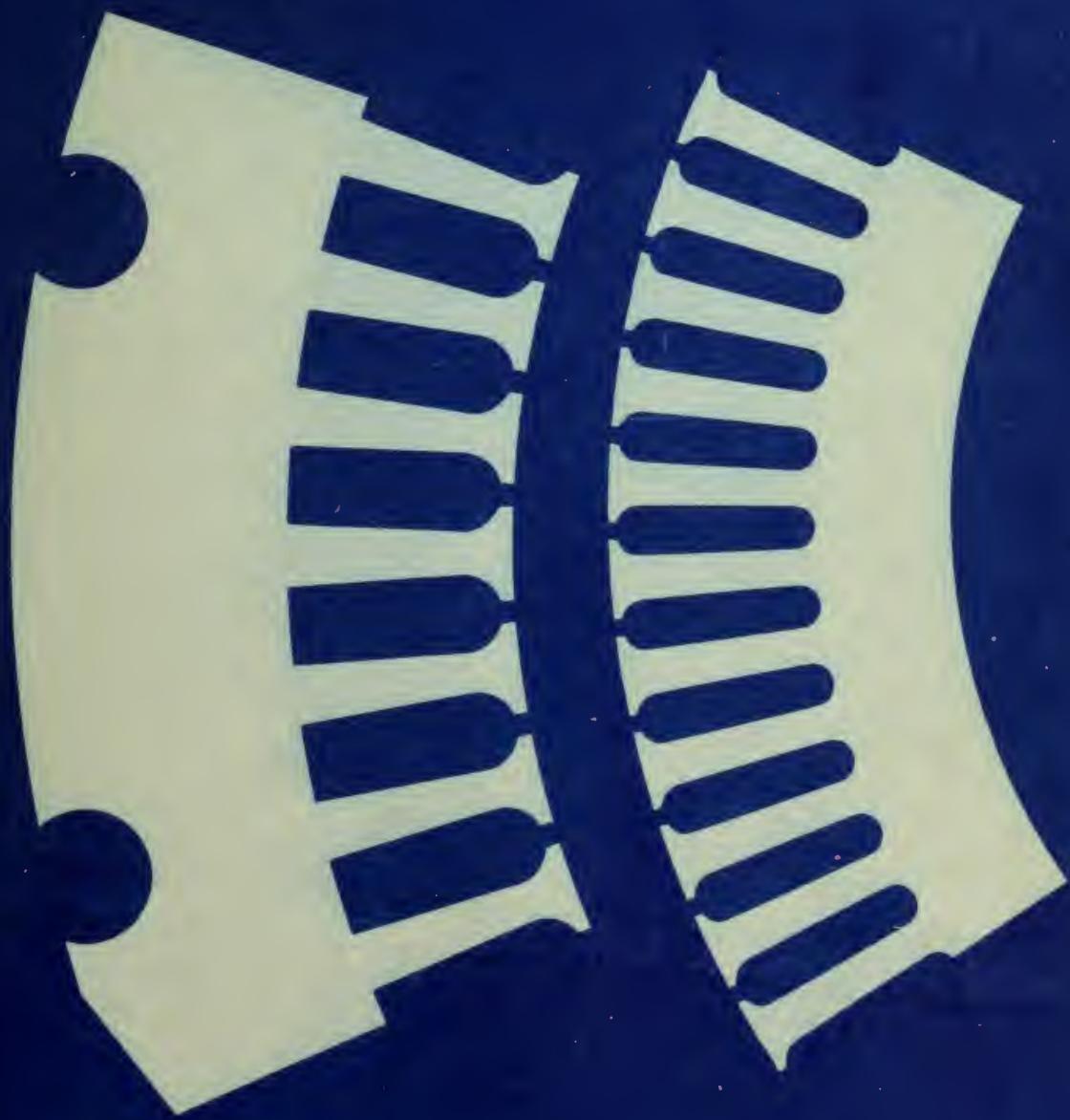
Fig 4.  
Rotor & Stator Stampings for  
2 1/4 H.P. Motors.





— Fig 5. —

Rotor & Stator Stampings for  
5, 7½ & 10 H.P. Motors.



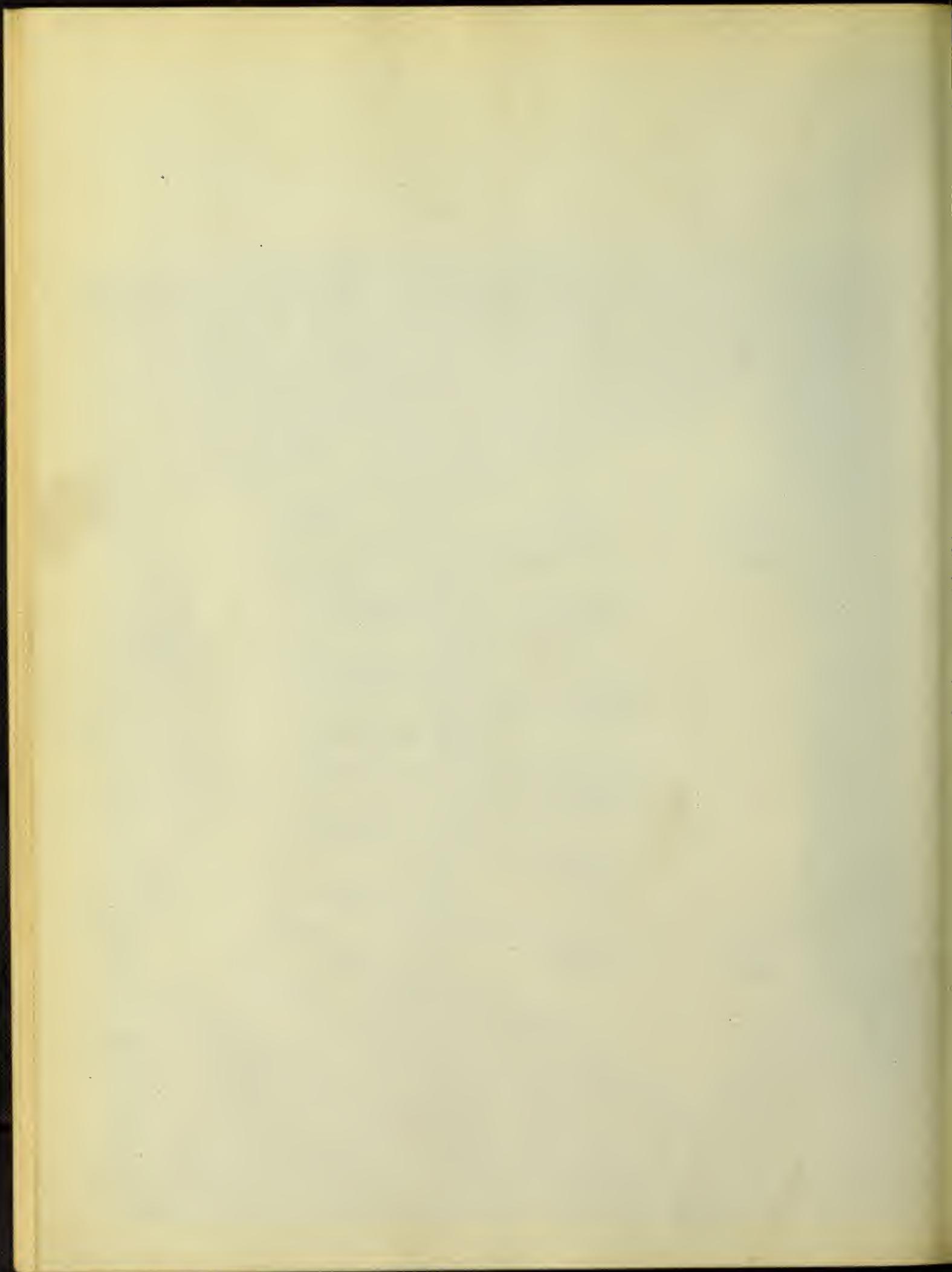
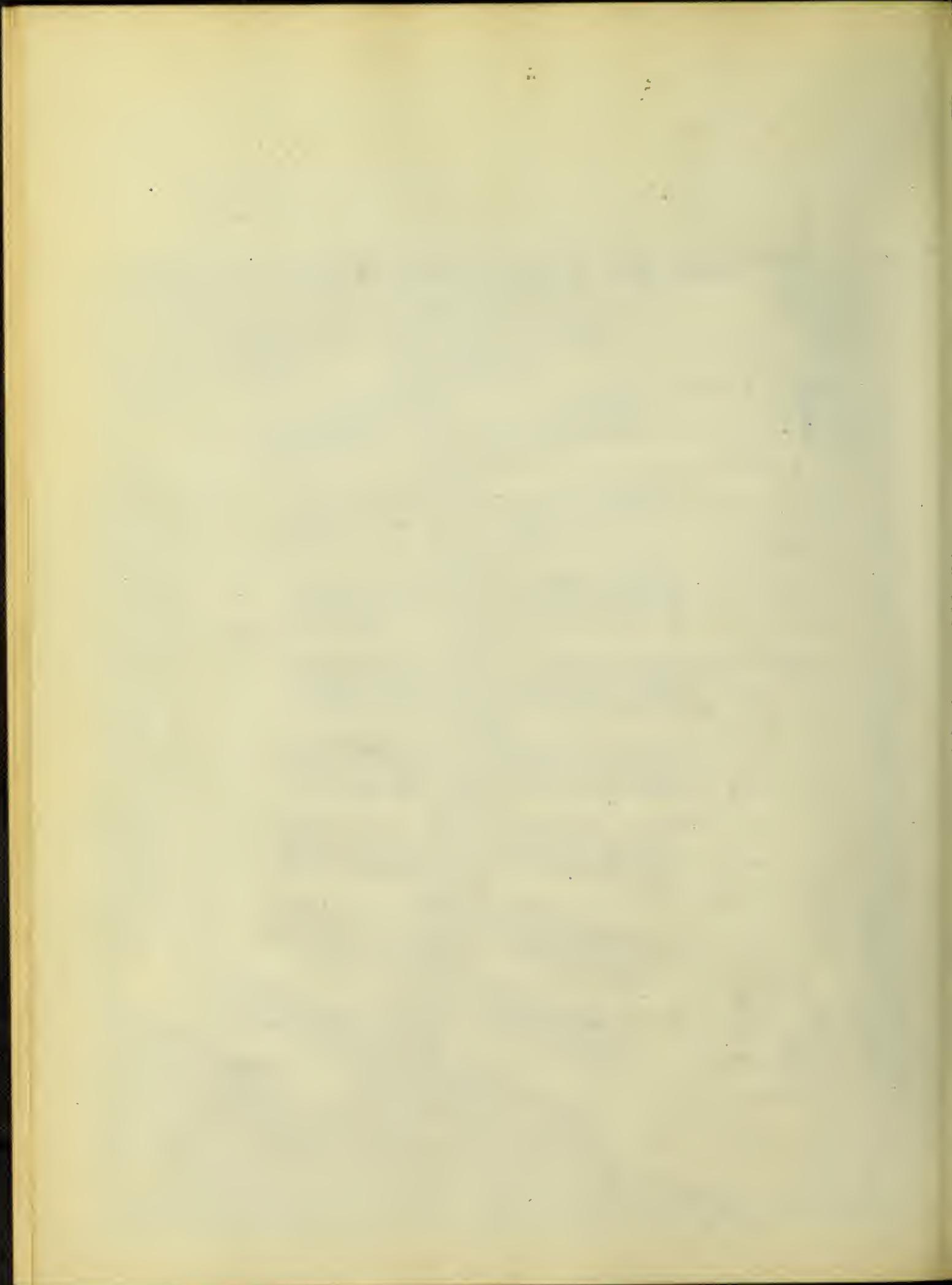


Fig 6.  
Rotor & Stator Stampings for  
15 H.P. Motor.





so-called "loop" to the stator winding.

Under normal starting and running conditions, the double pole switch in Fig. 7c is down, the single pole up. This is diagrammatically shown in Fig. #8. When both switches are down, connecting one line wire to this third terminal, the effect is the same as cutting out some of the field windings and a larger current flows through the remaining ones. The maximum starting torque is then developed. Fig. #9 shows this connection diagrammatically. When it is desired to cut down this excess of current a small so-called "auto-transformer" is used as shown in Fig. #7, by which arrangement the impressed voltage is reduced. Fig. #10 is a diagram representing this condition.

The motor is started with both switches up, and after the acceleration of the rotor has ceased, the single pole switch is thrown into the "loop" position. After further acceleration has ceased, the double pole switch is thrown down into running position and the single pole up or outside the loop, which is the position for normal running.

In Fig. #13 is shown a diagram of the winding on the stator, and the loop connection, for a four-pole, one-hundred & four volt machine. The "loop" terminal is marked "B" and the windings cut out by this connection are marked 1a, 2a, 3a and 4a. The two pairs of poles are connected in parallel.



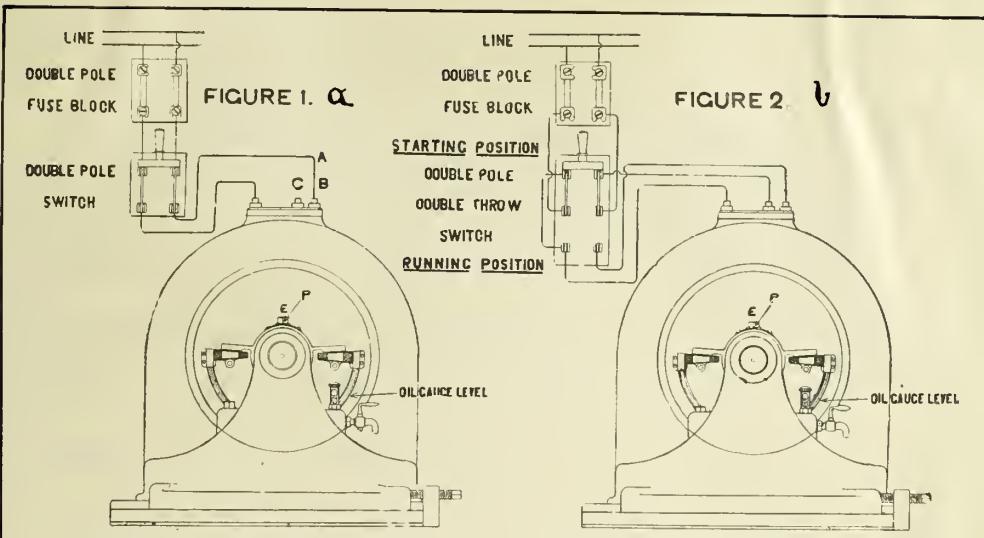
Fig 7

Fig. 156. Connections for Normal Torque.

Fig. 157. Connections for Abnormal Starting Torque.

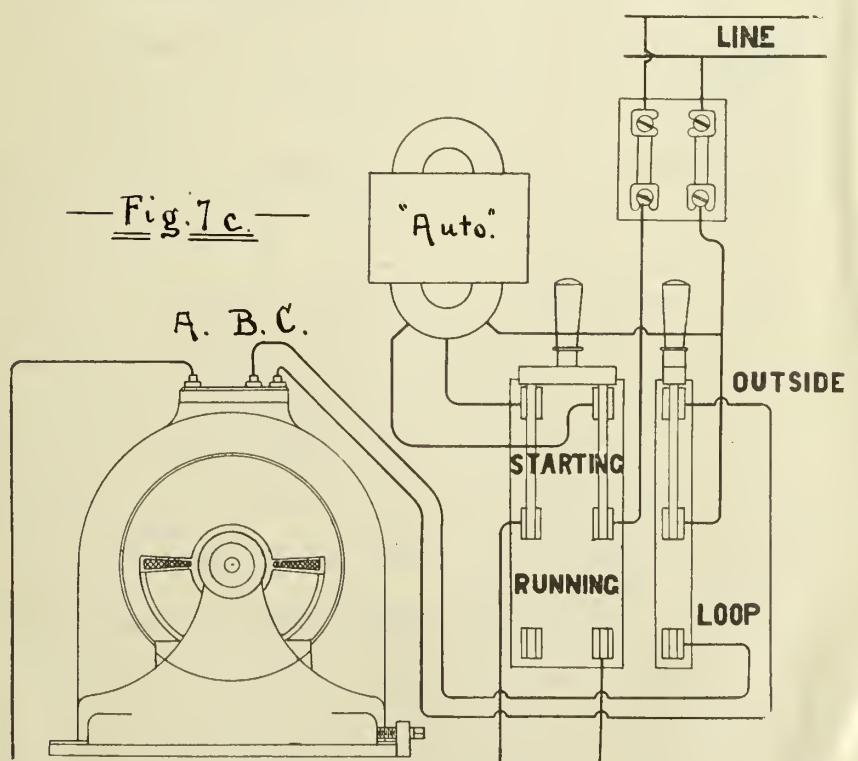
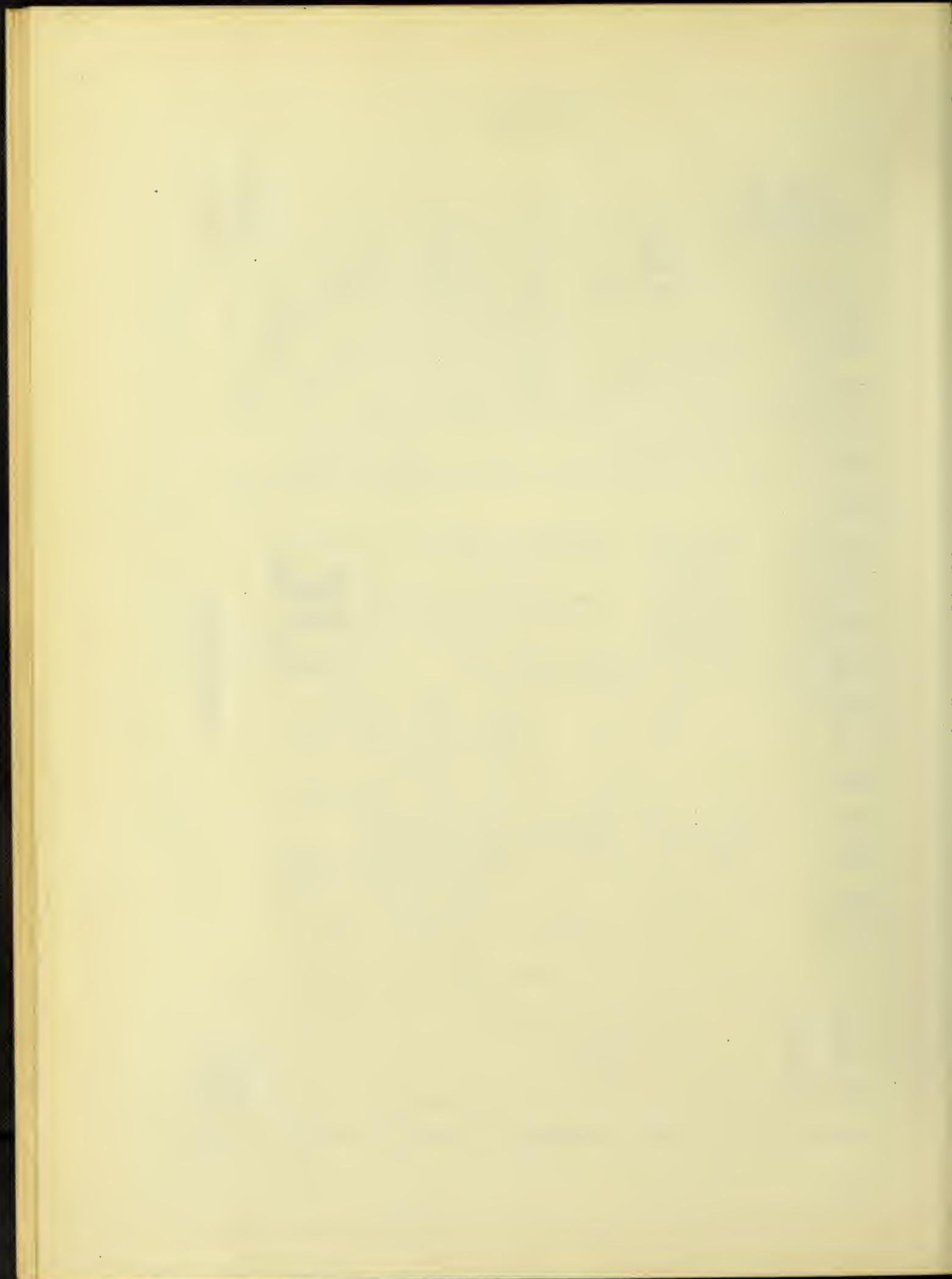
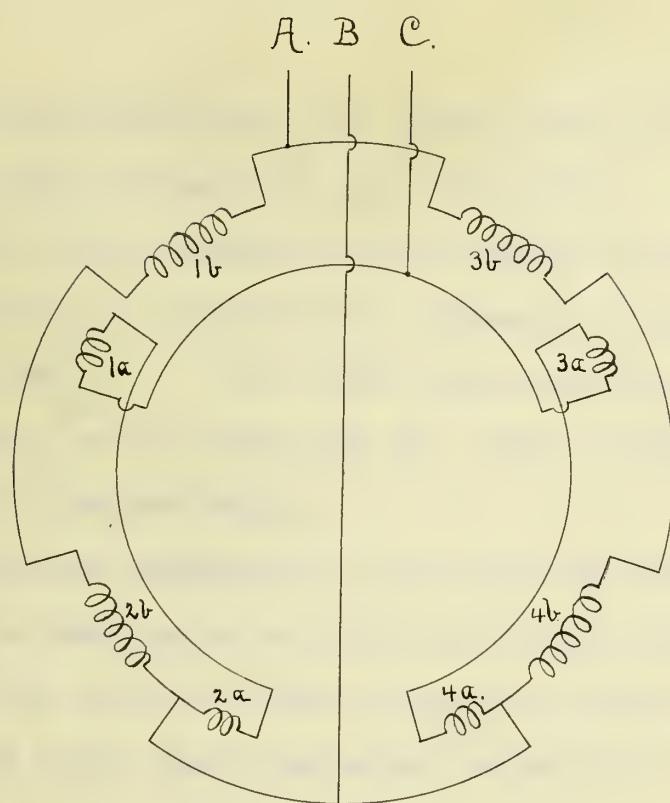
Fig. 7c

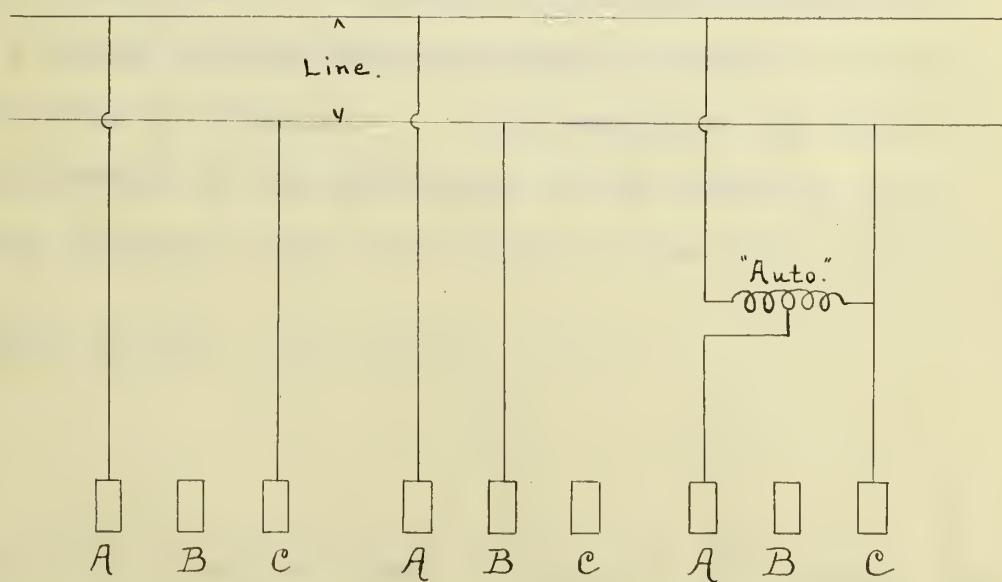
Fig. 158. Connections when a Small Reducing Transformer for Holding Down the Starting Current.

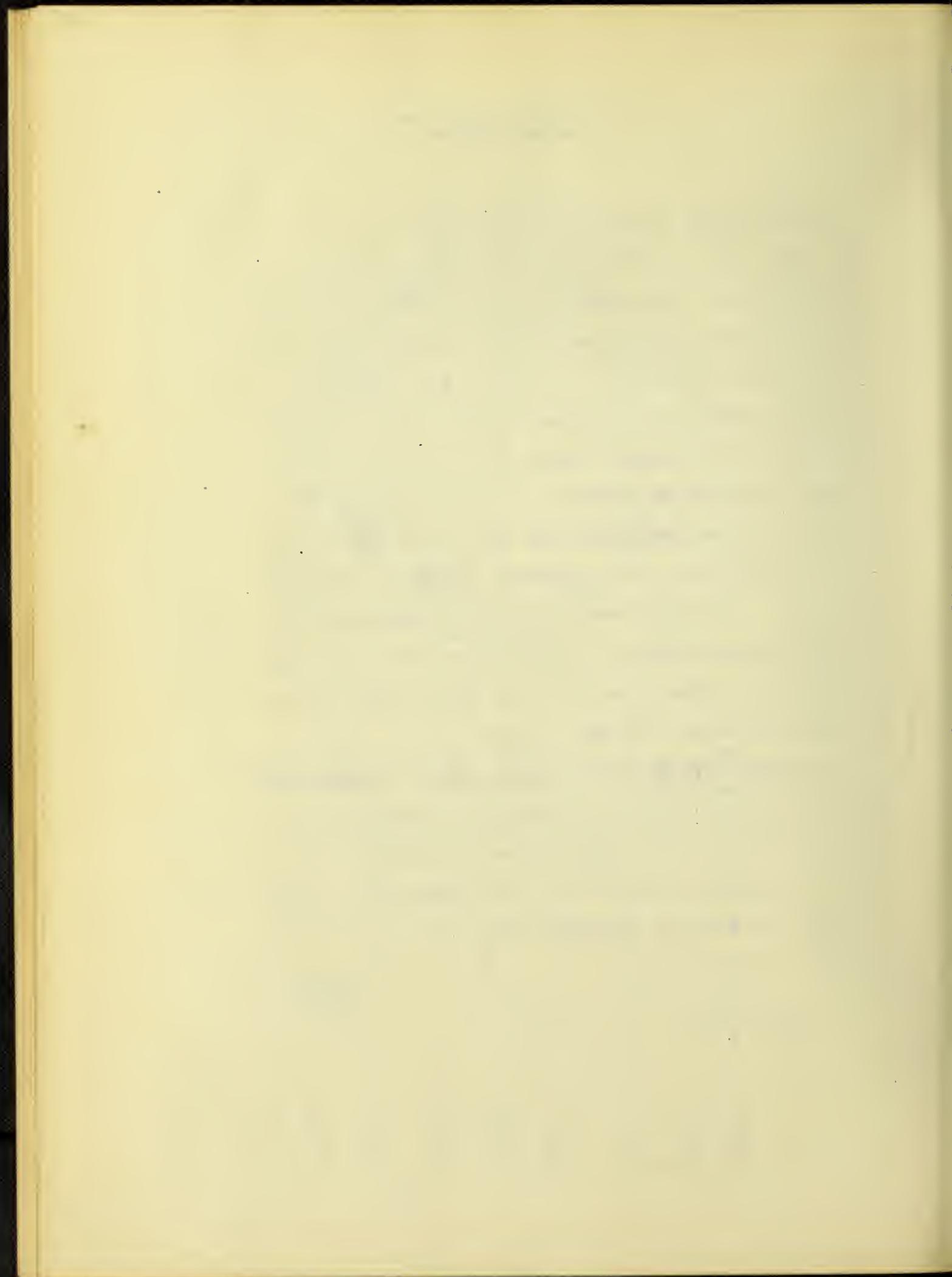


— Fig. 13. —



— Fig. 8. — — Fig. 9. — — Fig. 10. —





The windings constituting the stator poles are in the shape of flat coils threaded through the slots. This produces maximum field strength in the middle tooth of the pole, the intensity of magnetisation gradually diminishing toward either side. The coils are connected in parallel, or in series, as the case may be, for a terminal voltage of 104 or 208 respectively.

The machines are designed to run on 110 or 220 volt circuits, but are designated as 104 or 208 volt motors.

In making the tests of these motors the Prony-brake was used. The brake wheel was water cooled and of the form of cross section shown in Fig. #11, the radius being six inches. Hence in the tables, the torque in foot pounds is obtained by dividing the pull in pounds by two.

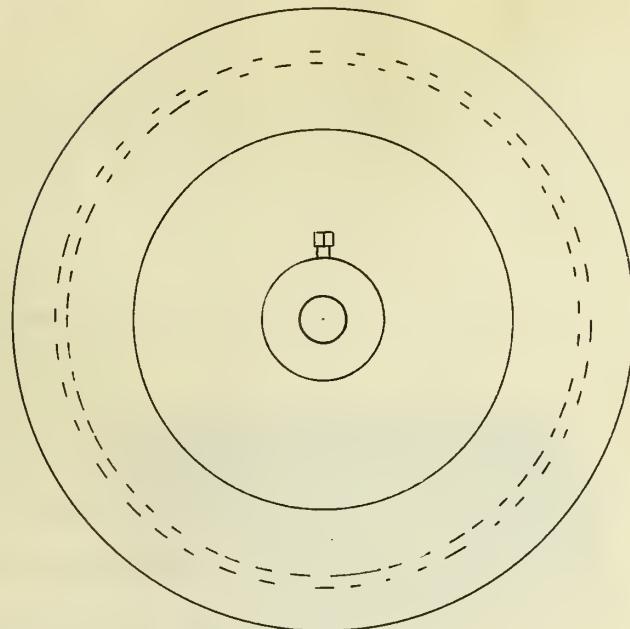
A spring balance was suspended above the wheel and a rope which hung from it, encircled the wheel and supported below the latter another spring balance in order to measure the difference of tension. The actual or net pull on the circumference is the difference of the readings of the two spring balances, minus the weight of the lower balance; or,

$$\text{pull in lbs} = [T_1 - (T_2 + W_t)]$$

The speed at any time was taken as equal to the speed of the

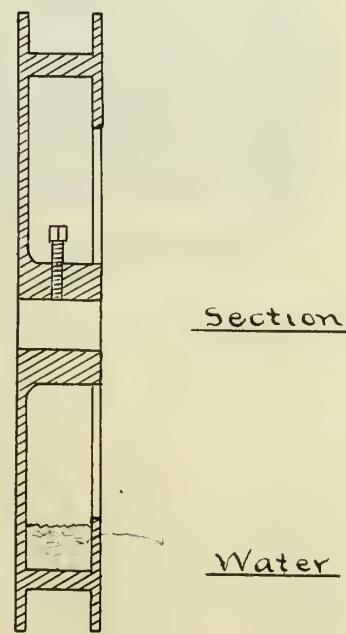
and of our many ways and existences suddenly with  
us. The state and moral humanities will be equal  
and we shall abide with the elements itself without another  
qualitative division, nothing being to utterated with out  
bearing in determination the action of. Only specific names  
will be required to us, and these will be chosen of the old  
existences still the old to the  
old still the old memory of becoming the medium of  
action day and to day an inseparable one but nothing  
and now-then with system need to affect with action of  
ours and to be before us and Earth itself of  
which created nothing but living in which nothing more to  
of action of names had in regard all, and not of names  
and of action of living and nothing  
but Earth with more elements are called after A.  
Europeans that Earth with elements, it was said when  
names of names of created nothing nothing called and called  
the living that the Earth of. indeed the names still  
and the nothing and the something and the nonnothing and  
names of names and the nothing and nothing called nothing and  
3. 8. 7. 4. 7. and at living

— Fig. 11. —



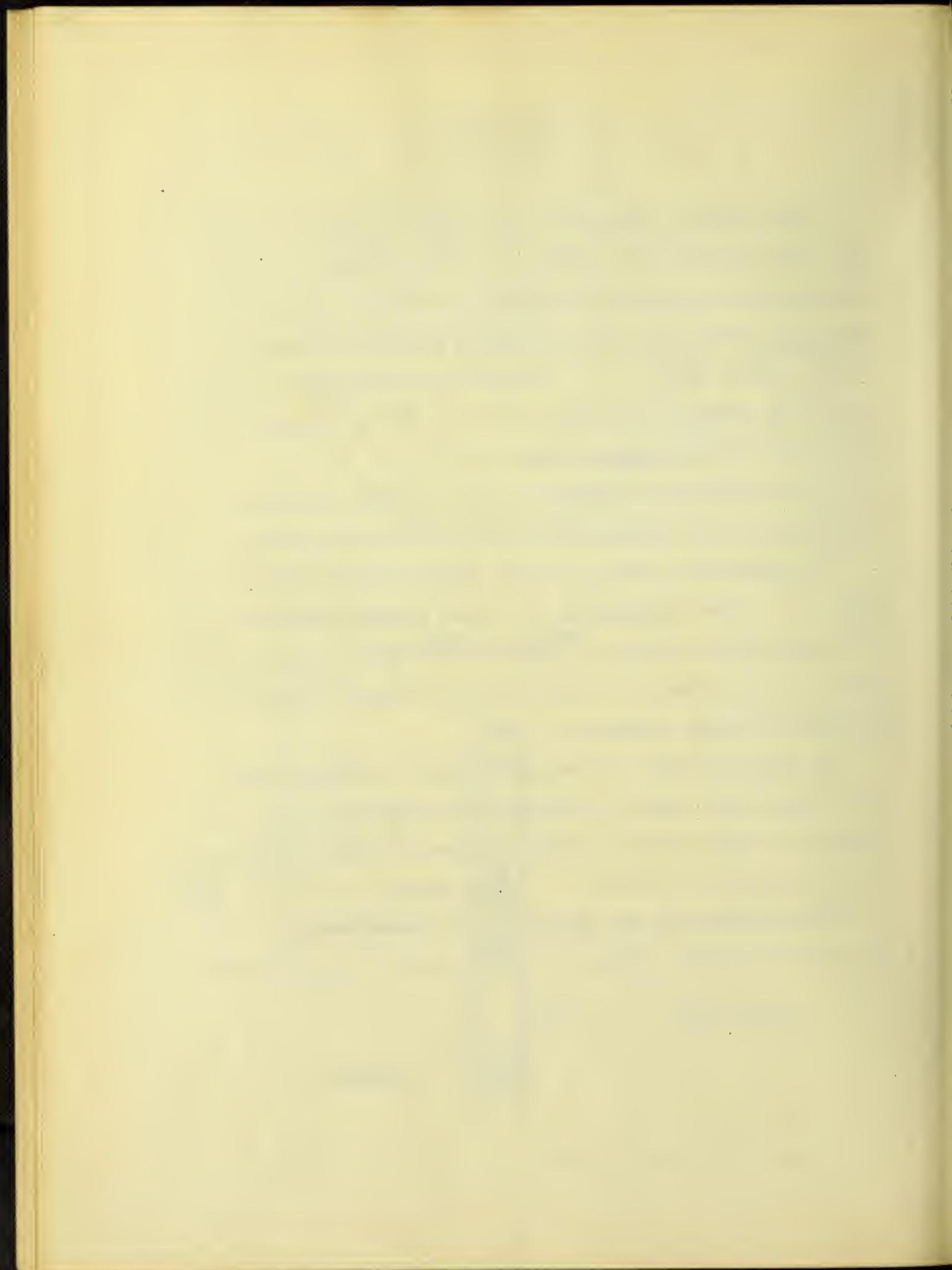
Elevation.

Brake Wheel

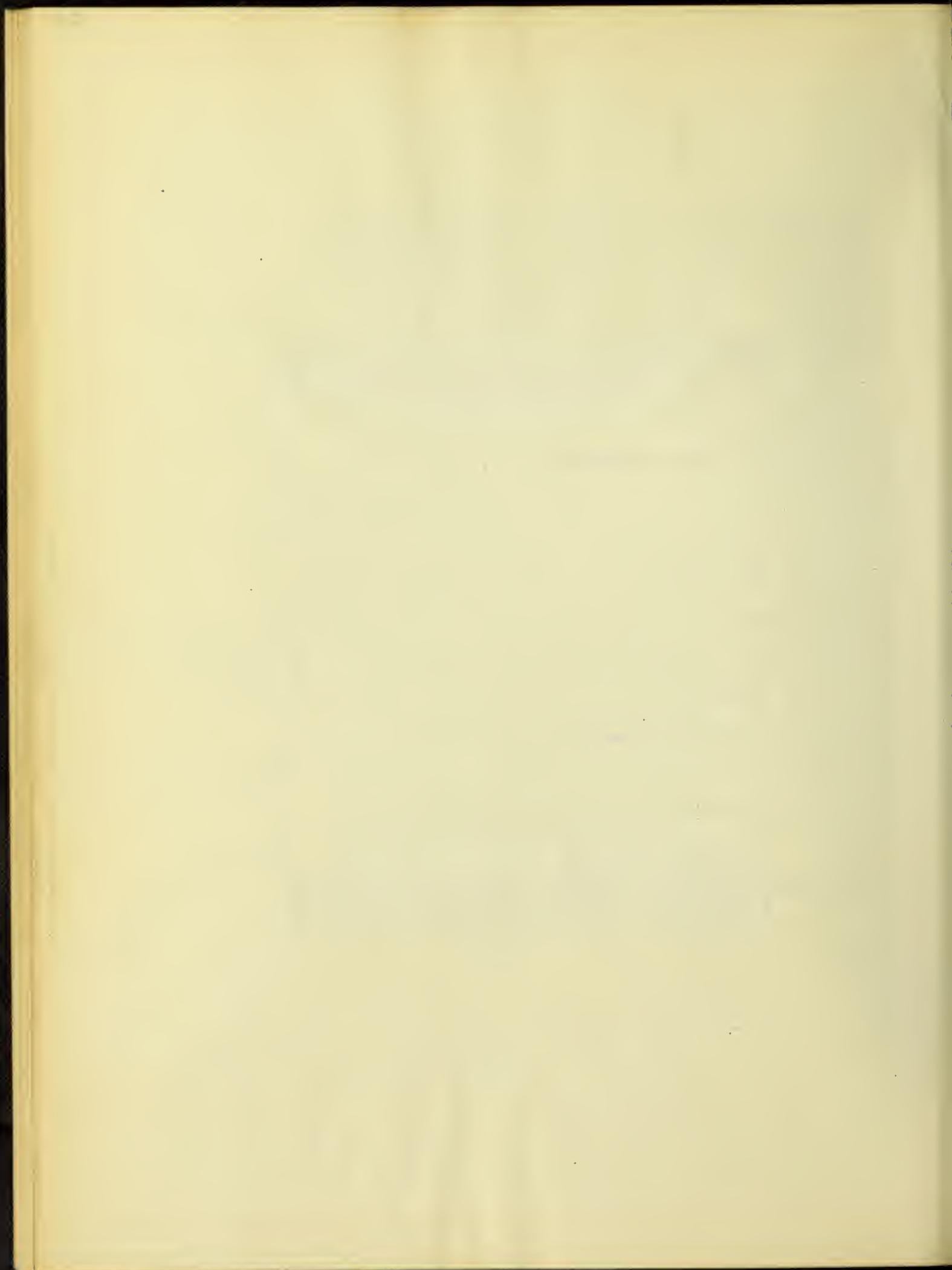


Section

Water







generator minus the slip of the rotor, expressed in revolutions per minute, since both generator and motor had the same number of poles. The method of determining the slip by use of the contact breaker was as follows;

In Fig. #12, A represents a small synchronous motor which was run from the same generator as the induction motor C. On the shaft of the synchronous motor was mounted a small brass wheel on which springs S and S<sub>1</sub> bear; S makes contact all the time, while the contact of S<sub>1</sub> is broken twice at each revolution of the wheel by means of two pieces of glass set in its circumference. On the induction motor was placed a similar breaker, having, however, only one contact break since the number of poles (4) of the induction motor was one half the number of poles of the synchronous motors. These two pairs of springs were placed in parallel and a current from a storage battery B. was passed through them in series with the single stroke electric bell D. The armature of the bell was pulled up by its magnets and held while there was current through the magnet coils. By this arrangement the bell would ring by the action of the opposing spring, whenever the circuit was broken simultaneously on both contact wheels. This method of using a closed circuit electric bell with the two contact breakers in parallel was adopted after trying many other devices. When two contact "makers" were used in series, the time of "make" was found to be so small, that the self

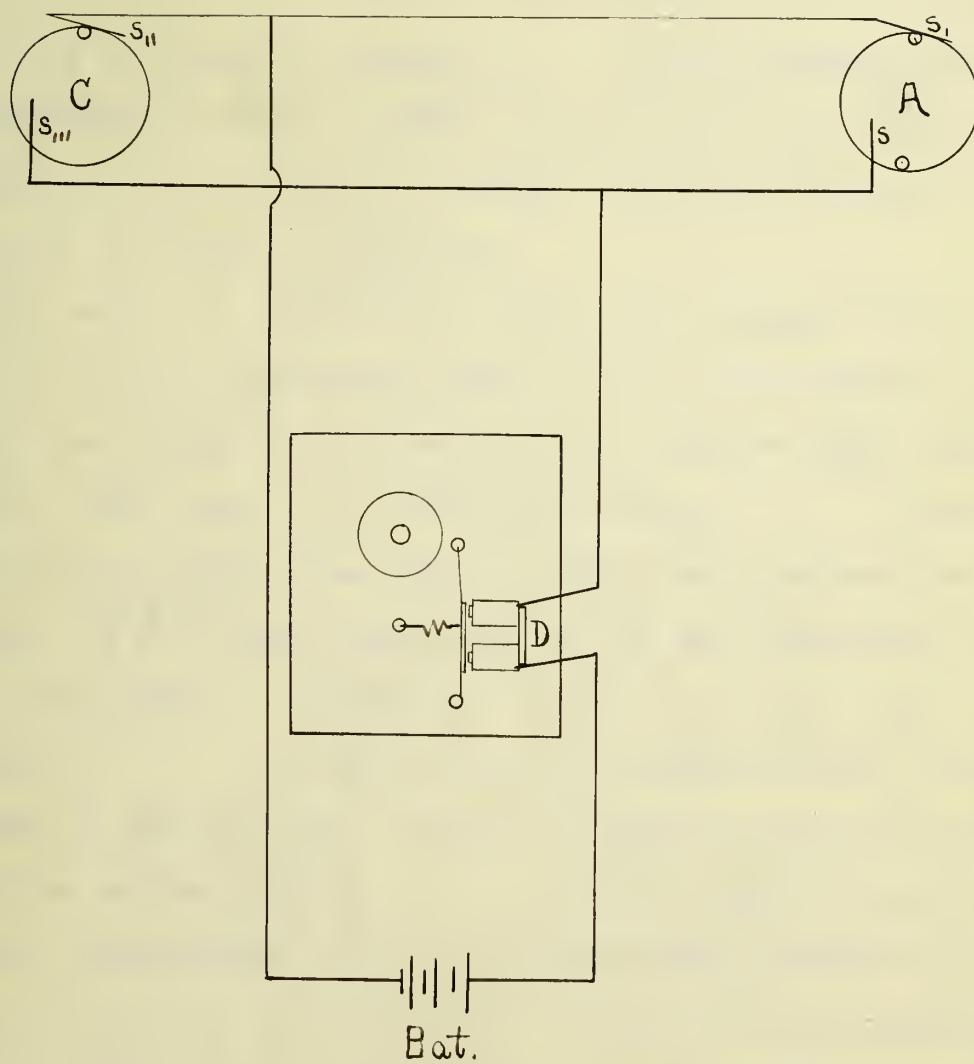
Janet L. Lofland, *Women, Violence, and the Law* (1992).

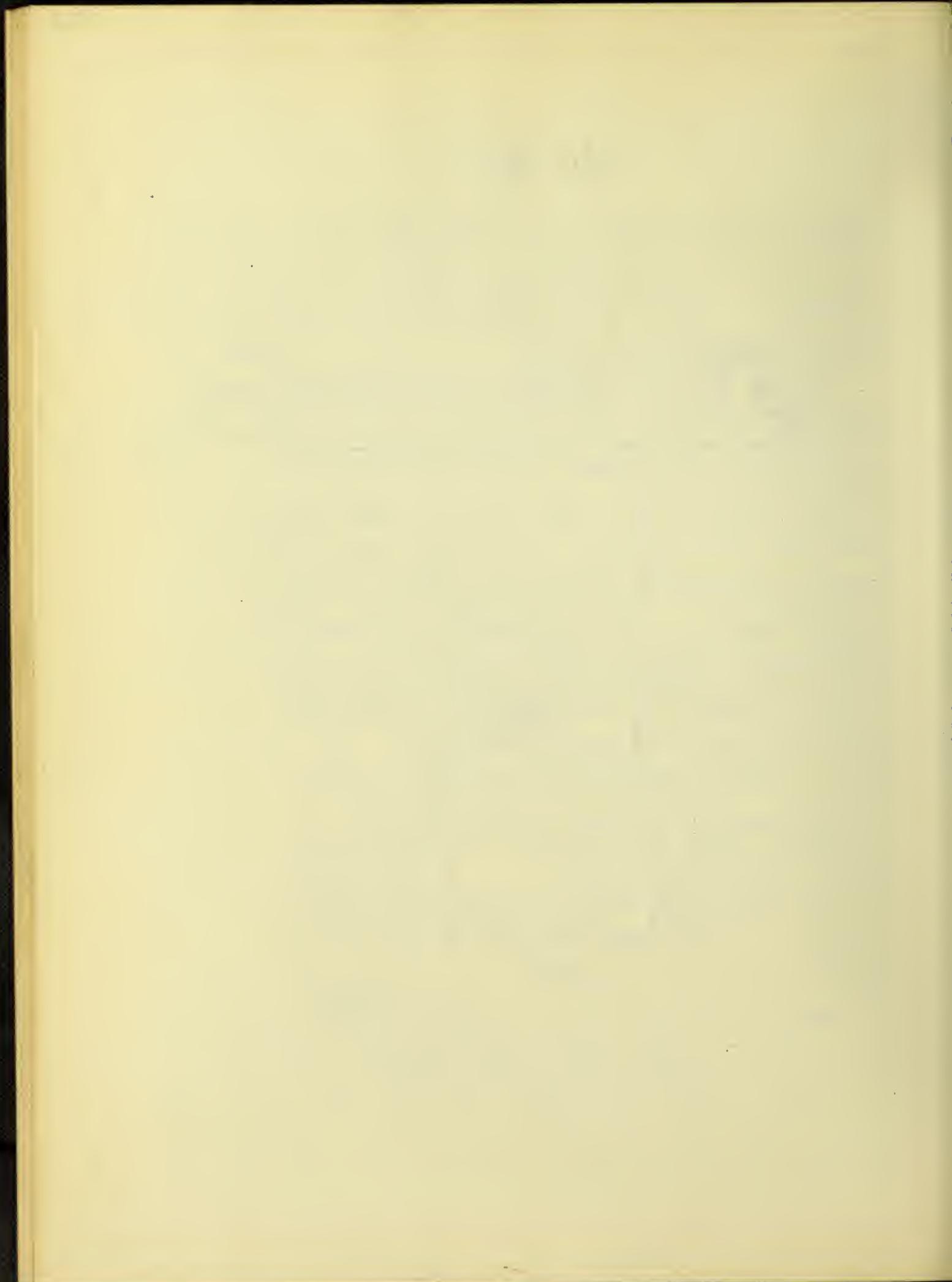
value, *sovereignty* lies in *discretion*. A 10% cut of  
funds will be offset with no reductions from the 10% cuts that have already  
been made. There is nothing else that's *sovereignty* but the *freedom* not to  
do *nothing* again. It would be best to *negotiate* and to *decide*  
what can be offset *without* it to *begin* with *what* will  
not be *reduced* by *merely* not the *amount* of funds will be reduced  
in *discretion* and *nothing* but *freedom* not to  
overlook.

and many small features and glass, several small fragments still  
remain. Since you have written additional add to (A) under (1) broken  
and small fragments. Several pieces of glass are still to add to (A) under  
(1) broken and small fragments. Add following to (B) under (1) broken  
and small fragments or less following of broken glass, when anything to add  
to (B) under (1) broken and small fragments having any of fragments missing  
add to (B) under (1) broken and small fragments.

Business law would define this arrangement as a *franchise*, and  
such arrangements are very common. Franchises are agreements  
between existing businesses to enter into a new business. These franchises  
allow franchisees (not the franchisors) control over business and  
they often expect franchisees to give up a portion of their  
profits to the franchisor. Franchising is a common business  
arrangement, and it is often used in the food and service industries.

—Fig. 12.—





induction of the bell coils would not permit of establishing sufficient current to pull the bell armature over to the magnet during the interval of contact. This interval, however, was sufficiently long to permit the spring to pull the armature away at the instant of "break" - when two contact breakers were used, connected in parallel.

The action in detail was as follows; suppose both  $S_1$  and  $S_2$  to be on the insulating points of the two contact break wheels; the spring is then holding the armature away from the magnets, since there is no electric circuit. If the break wheels revolve, the springs will touch the brass, making contact, and the magnet will pull up the bell armature, holding it until the breaks in A and C, occur again simultaneously. At such instant the magnet again releases its hold of the armature, causing the bell to ring, through the action of the spring. If the induction machine revolves with exactly twice the speed of the synchronous motor, the bell will ring once for each revolution of the induction motor or twice for each revolution of the synchronous motor. However, when a load is put on the induction machine, its speed will drop to a smaller constant value, depending upon the load. If it loses one complete revolution the breaks in A and C will occur again simultaneously, and the bell will ring.

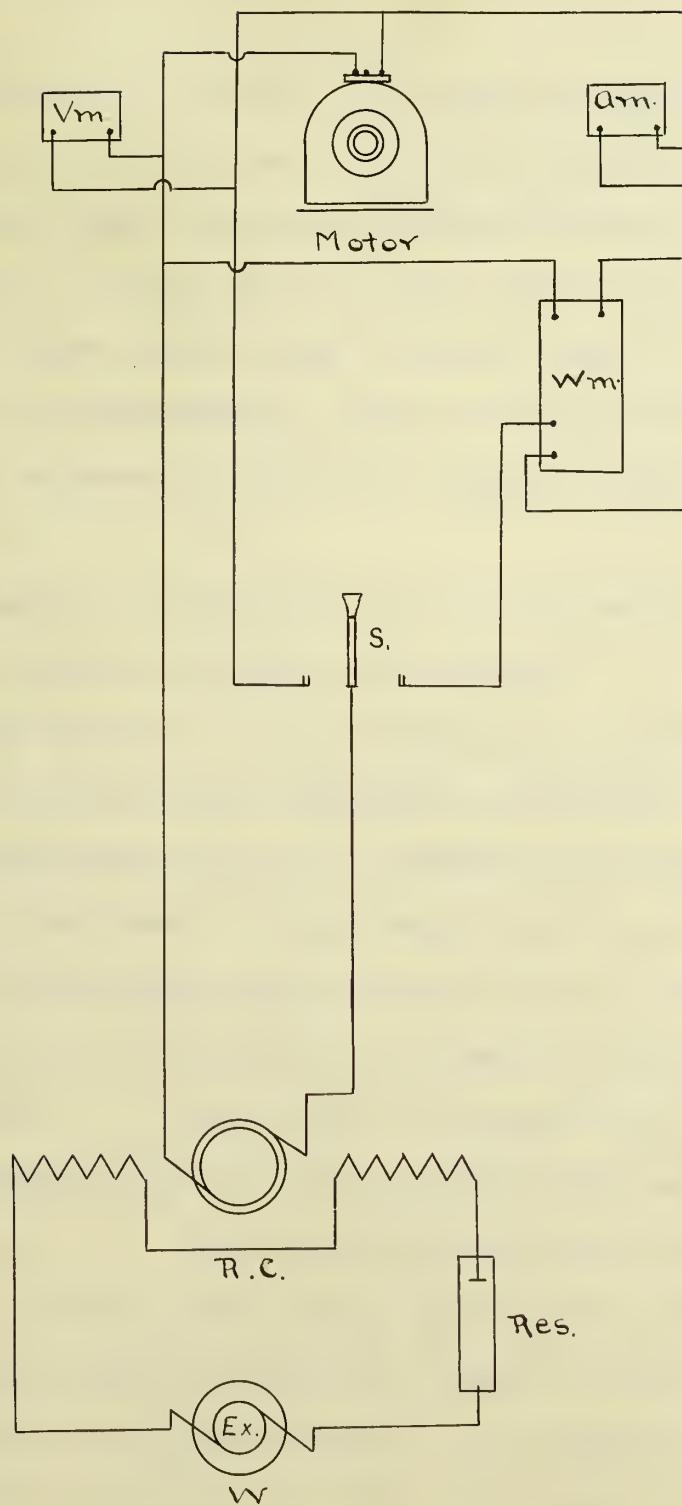


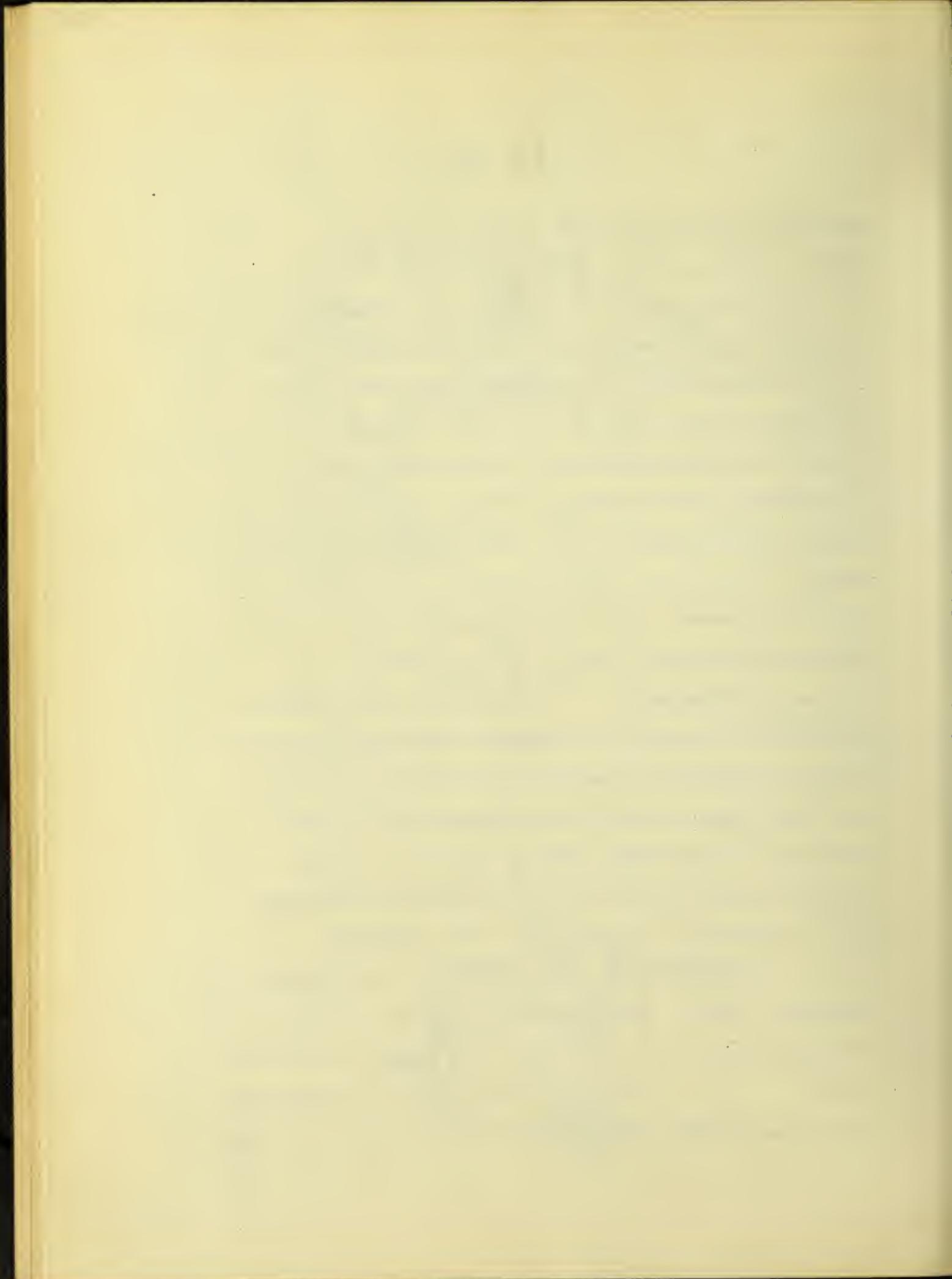
This interval represents one revolution of slip. Counting the time for a certain number of such intervals or of rings, gives the slip in actual revolutions per minute, from which the percentage slip is obtained. Each motor was tested at 75, 90, 104 and 120 volts, the voltage being kept constant under all loads, in each test. The instruments for testing were connected as shown in diagram Fig. 14. M represents the induction motor receiving current from the  $7\frac{1}{2}$  K.W., G.E. rotary converter R.C. The fields of the latter were excited by the 3 K.W. Weston machine and the voltage regulated by means of the water rheostat, Res. Wm represents the Weston wattmeter. Am the Thomson ammeter and Vm the Weston voltmeter. S represents a single pole, double throw switch, by means of which the instruments were cut out of circuit on starting to avoid the heavy rush of current. The motor was loaded gradually by increasing the tension on the brake rope, and readings taken at different loads. The voltage was kept constant by regulating the excitation of the rotary converter by means of the water rheostat.

The values observed were volts at the terminals of motor (constant) amperes, true watts input, pull in pounds on the circumference of the brake wheel, and slip in revolutions per minute. From these values were calculated the brake horse-power output, the apparent watts input, true efficiency,



—Fig. 14.—





apparent efficiency, power factor, idle watts, and percent slip.

To compare the results, the values obtained were plotted in a full set of curves on a "percent of full load" base.

To obtain some data and information about the motors, we visited the factory of the Wagner Electric Manufacturing Company and there made a test on a 208 volt, 10 H.P. induction motor by their method, using the University of Illinois instruments connected up with the regular shop testing instruments.

The essential difference between the shop method of testing and our own is in loading the motors. In the shop the motor is belted to a separately excited direct current generator, which has been carefully calibrated, and curves of motor horse-power output at different generator plotted. The motor is run from a transformer, and the voltage at the terminals of the former is adjusted to 104 or 208 volts as the case may be, by cutting out primary or secondary turns of the latter. Each motor is tested at no load, half - full - and maximum load, on both the "outside" and the "loop" connections. The desired load is put on the generator and readings of the motor volts, amperes and watts input are taken. The "slip" at different loads is not observed. The agreement of the instruments of the Wagner Co. with those which we took with us can be seen from table

and the other will continue to be considered.

With your immediate return the following will complete all  
your legal acts by passing a no across the law. Elect a  
council and have instruments for acts now possible of  
completion without recall and by recall will be able to  
cancel all of this but as far as is now true the council  
will be concerned with nothing. (After receipt of notice and  
order you will have only 30 days to act.)

The council will then consider returning all  
of the above and will do so if all the law has not  
been passed. Your 30 day time limit is not to be violated  
and the time limit is to be observed and the council  
cannot exceed this time limit. The law will be  
enacted and the council will recall over all 30 days and  
in 30 days you as well as yourself will be allowed  
to do what you have done in the 30 days of your time but  
you will not be allowed to do what you did in the 30 days.

Should you find that the law is not passed then the  
council will do the same and the law will be  
enacted. The 30 day limit is to be observed and the council  
will not be allowed to do what you did in the 30 days.

In Plate I the entire set of curves for the 2 H.P. motor at nominal voltage (104) are plotted. The efficiency curve is highest at about 75% of full load, reaching a value of 77.2 and bends down at full load decreasing as the machine is overloaded. The idle watts increase nearly in a straight line to 75% load and then rise more quickly until a value of 2540 watts is reached at full load. The maximum power factor occurs at about full load and decreases slightly at more than 100% of load, corresponding to the increase of idle watts.

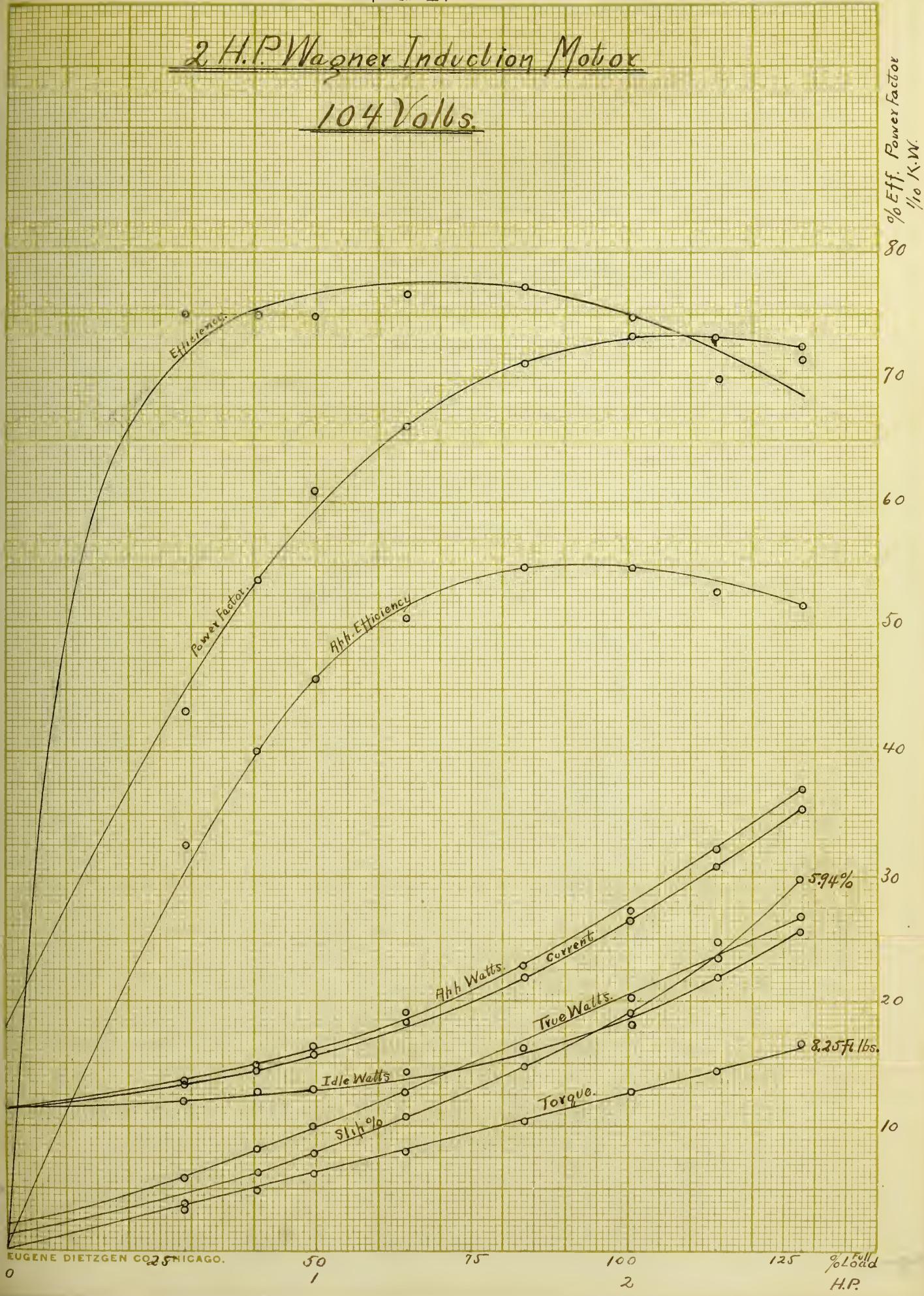
In this discussion we mean by "idle watts" not the no load watts, but the product of the apparent watts or volt-amperes, by the sine of the angle of lag.

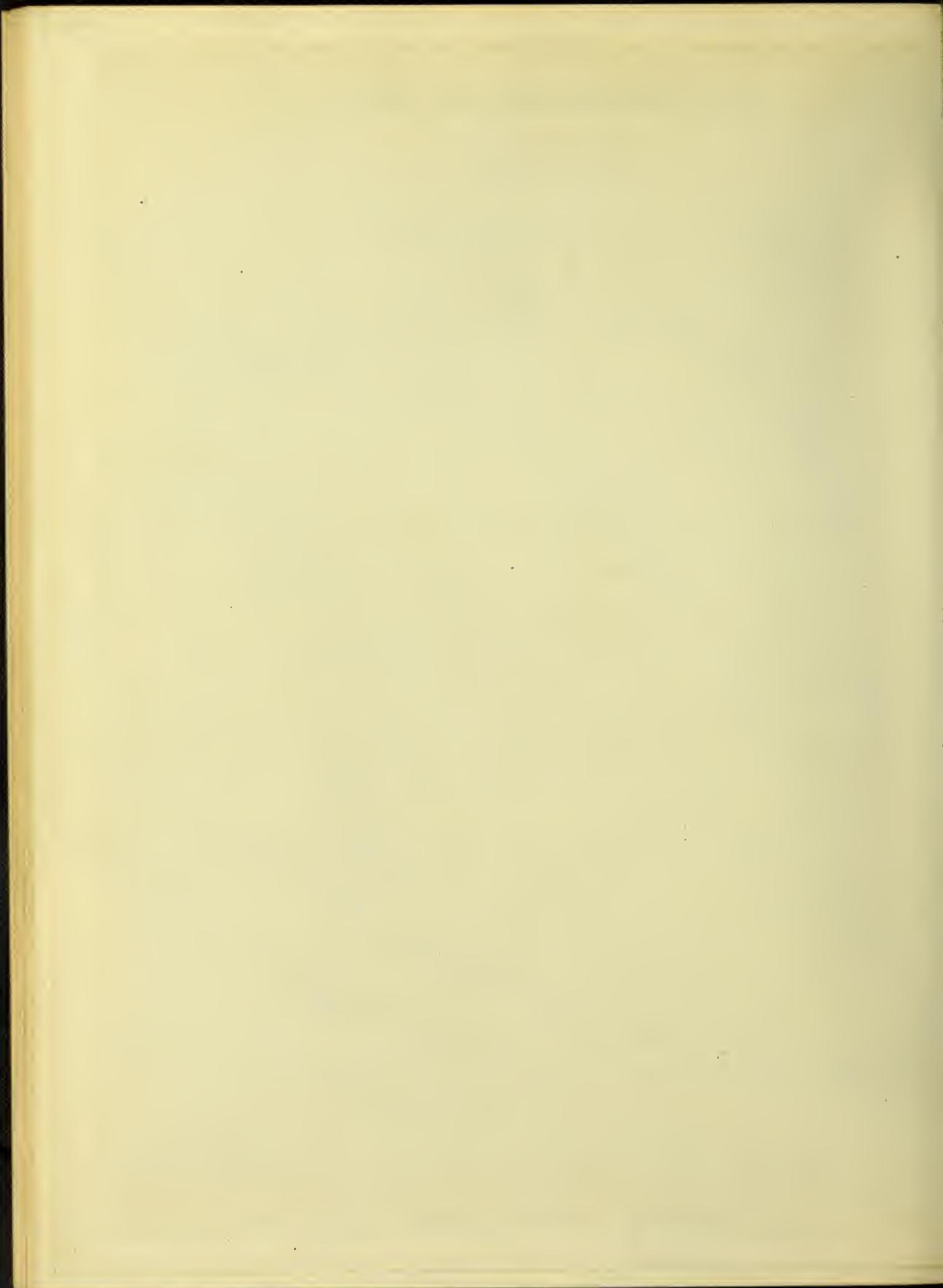
The maximum torque is 8.25 foot pounds and the torque curve is of course a straight line when plotted on a horse power or % load base.

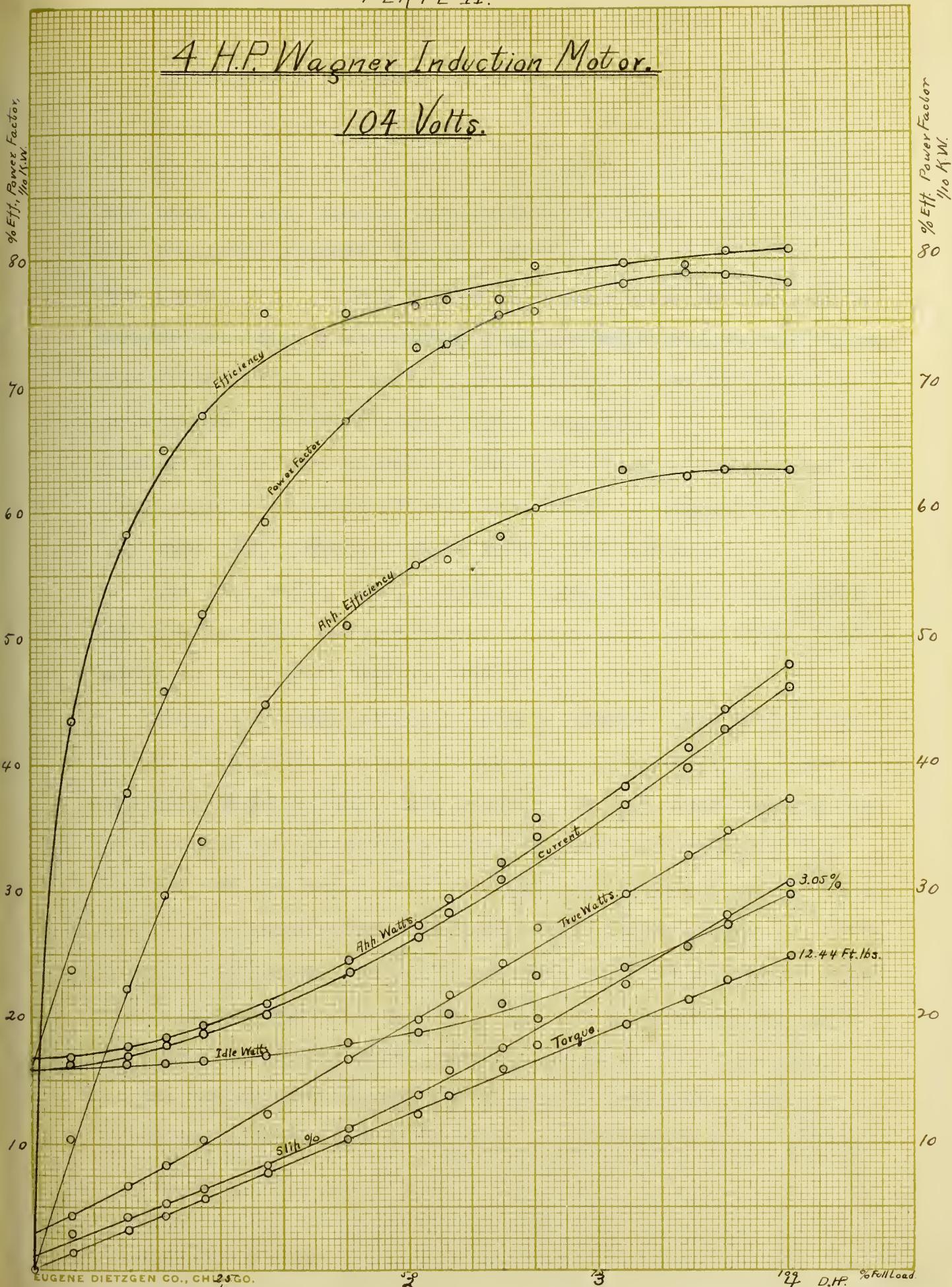
In Plate II corresponding curves for the 4 H.P. motor are plotted. In this motor the efficiency had not reached a maximum at full load, at which point its value was 80.5%. The power factor reaches a value of 79% at 87-1/5% of full load. The maximum torque is 12.44 ft lbs. and on attempting to go beyond this the motor fell "out of step". These tests were all run from the rotary converter of 7.5 K.W. capacity and it would certainly seem that if the motor could carry an excess of rated load that a 7.5 K.W. generator would be sufficient.

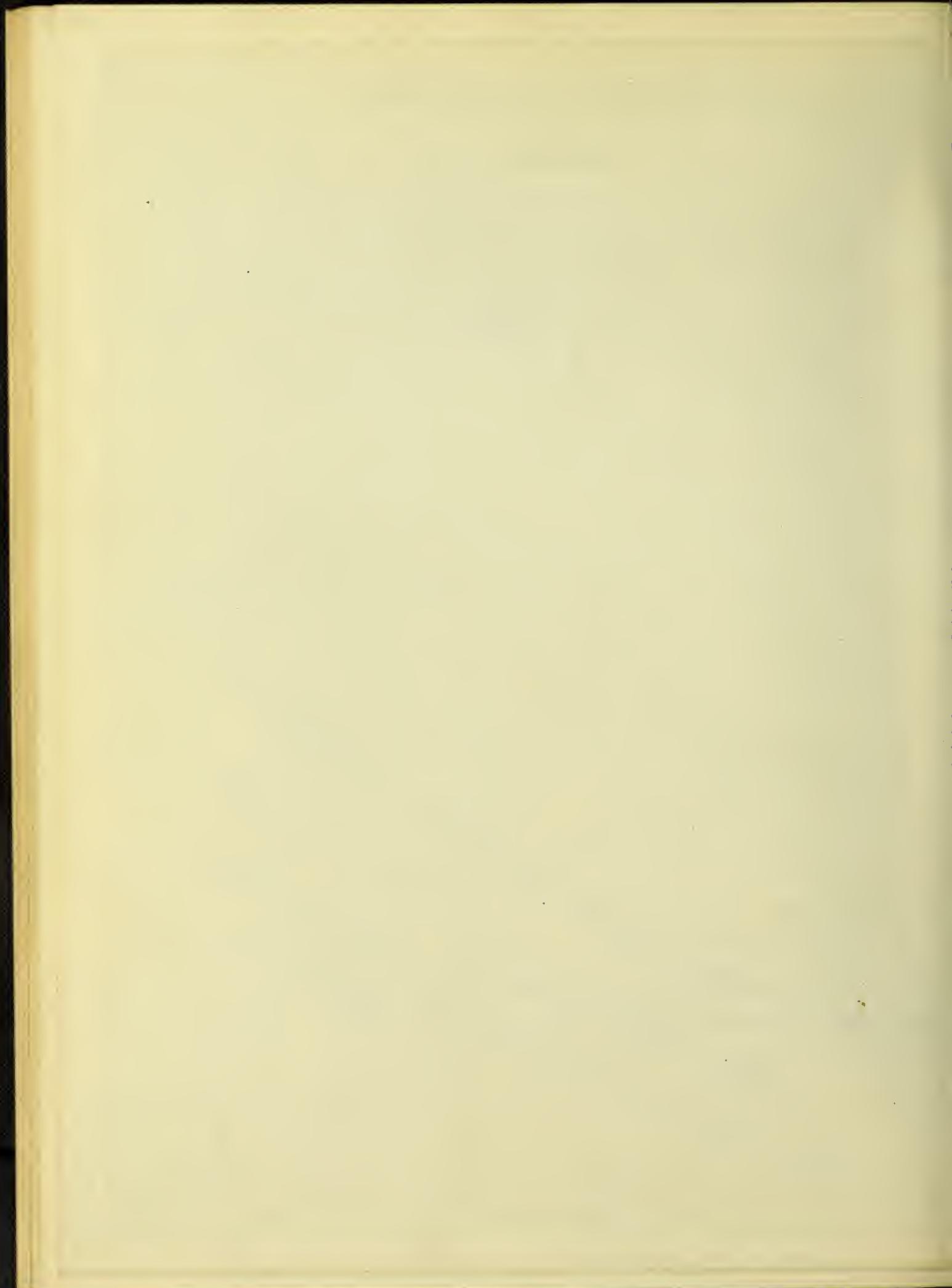


2 H.P. Wagner Induction Motor  
104 Volts.





4 H.P. Wagner Induction Motor.104 Volts.



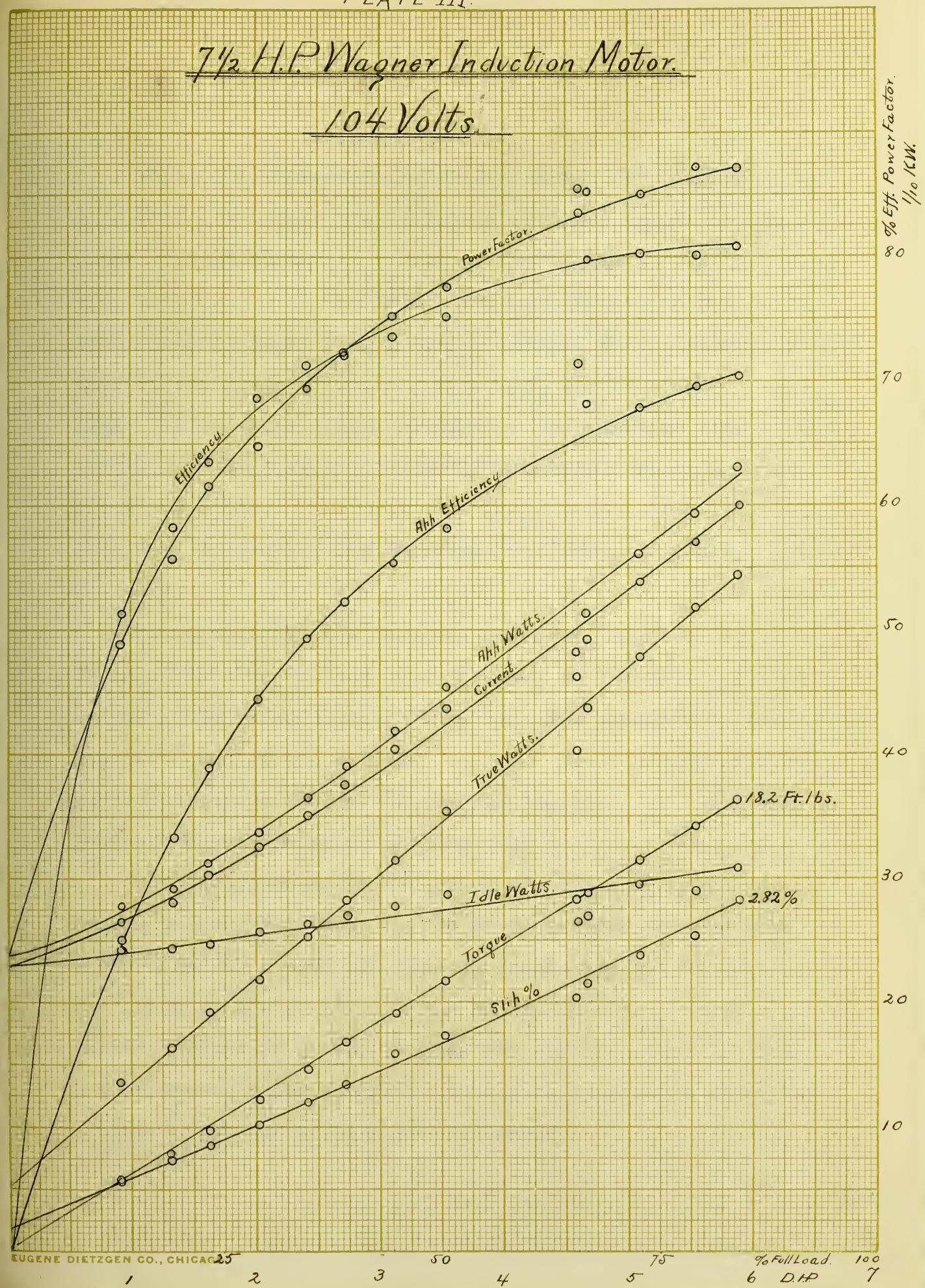
to supply the necessary power. We stated this case to the engineers of the Wagner Co., adding that the voltage was held at 104, and the explanation given was, that either the generator capacity was not sufficient or that our line was too small.

They stated also that they had had similar trouble at times when running from a static transformer, being compelled either to put in a transformer of larger output or to wind the transformer for higher voltage. The statement of the rotary converter and line capacity being insufficient hardly seems to fit the case since we transmitted under the same conditions 5.88 H.P. to the  $7\frac{1}{2}$  H.P. motor.

The idle watts reach a value of 2960 on this 4 H.P. motor and are far from being constant rising in a curve whose bend seems to be between 50% and 75% of full load.

Plate III shows curves of the  $7\frac{1}{2}$  horse power motor though we were unable to run above 5.88 H.P. Insufficient line capacity might in this case account for the motor falling out of step but the true watts supplied were only 5445 and the E. M. F. at the motor terminals was kept constant so it would seem that a higher output should have been obtained. The maximum efficiency was 80.7% occurring at 6 horse power. The power factor was high reaching 87%; the idle watts were only 3070 and though the curve seemed to rise at half load the values beyond that seemed to be less in proportion so the curve was constructed as shown. The maximum slip is 2.82%



7½ H.P. Wagner Induction Motor.104 Volts.

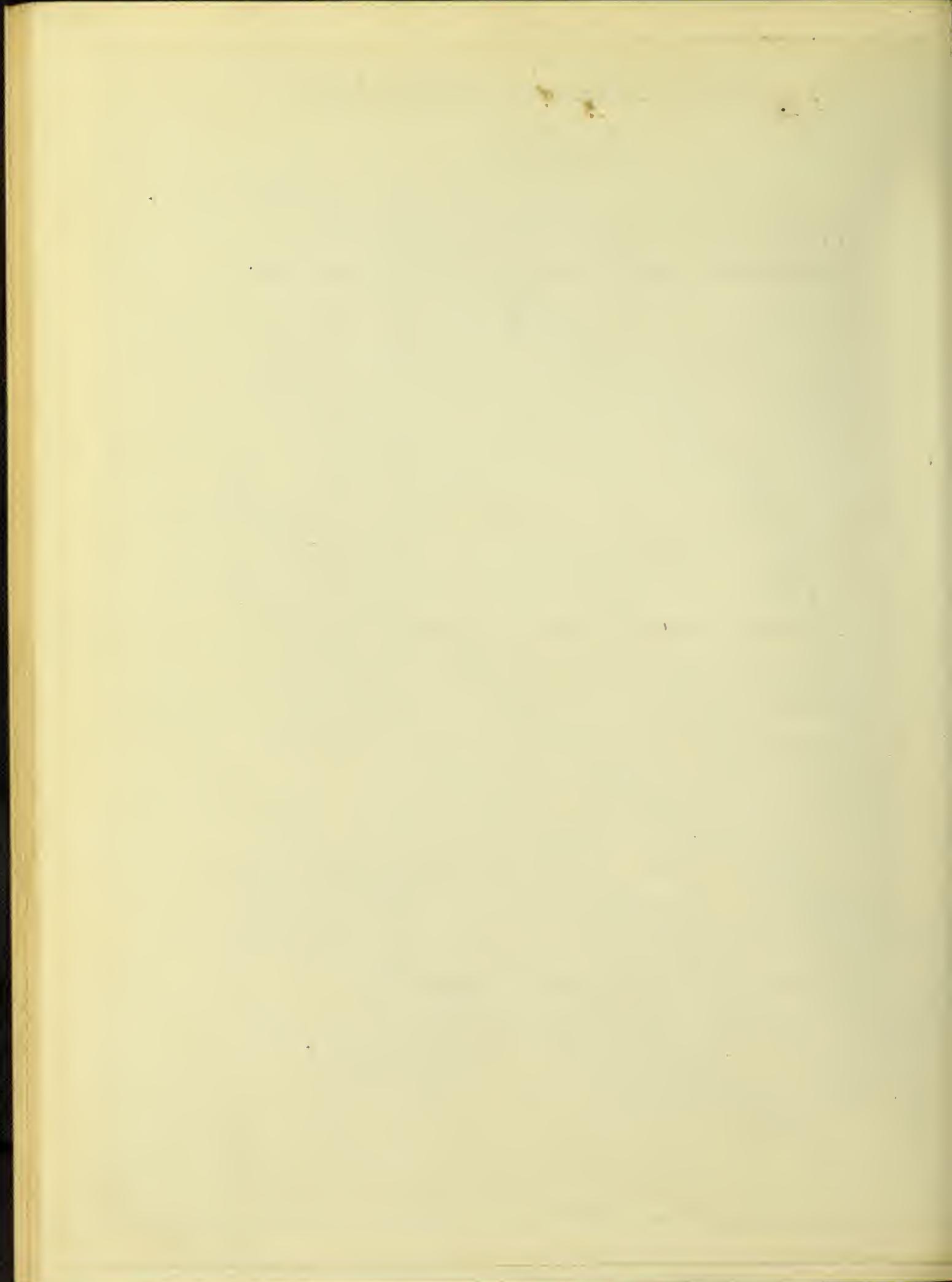


Plate IV. shows idle watts and efficiency plotted on a true watt input base the maximum efficiency occurs on the lower voltage curves at a smaller input than on the high voltage curves.

The idle watts curves seem to cross in such a manner as to have a common tangent which intersects the axis of ordinates on the negative side of the origin. In Plate V this tangent line crosses on the positive side of the origin and the curves of idle watts become flatter than in the 2 H.P. motor.

In this Plate the highest efficiency occurs at 104 volts, the efficiency at 120 and 90 being almost the same.

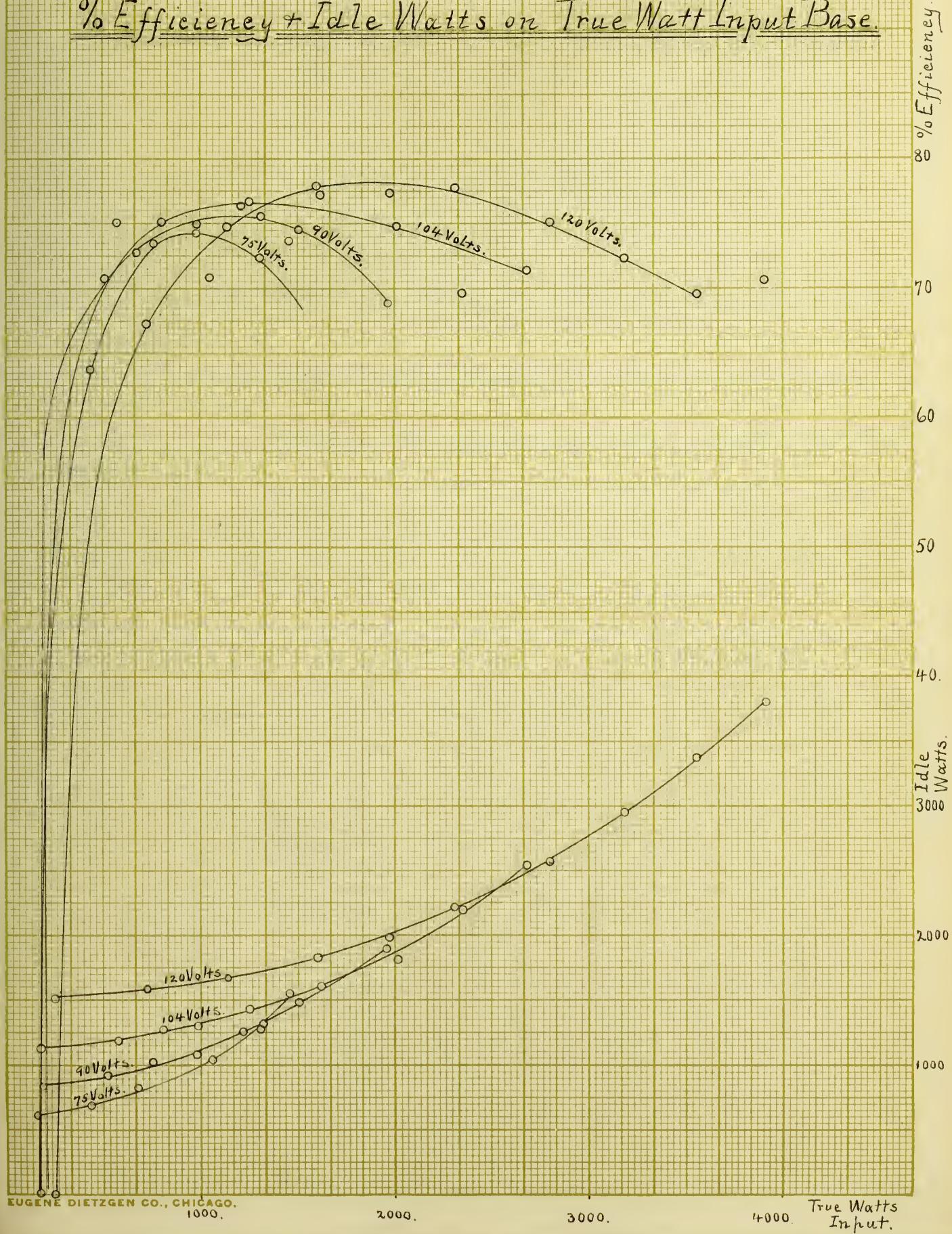
Plate VI shows the same curves for a  $7\frac{1}{2}$  h. p. motor and in this Plate we see the same tendency of the idle watts curves to form the tangent line, the line crossing on the positive side of the origin. The tendency of the curves to become flatter is also noticeable. The maximum efficiency being on the 120 volt curves.

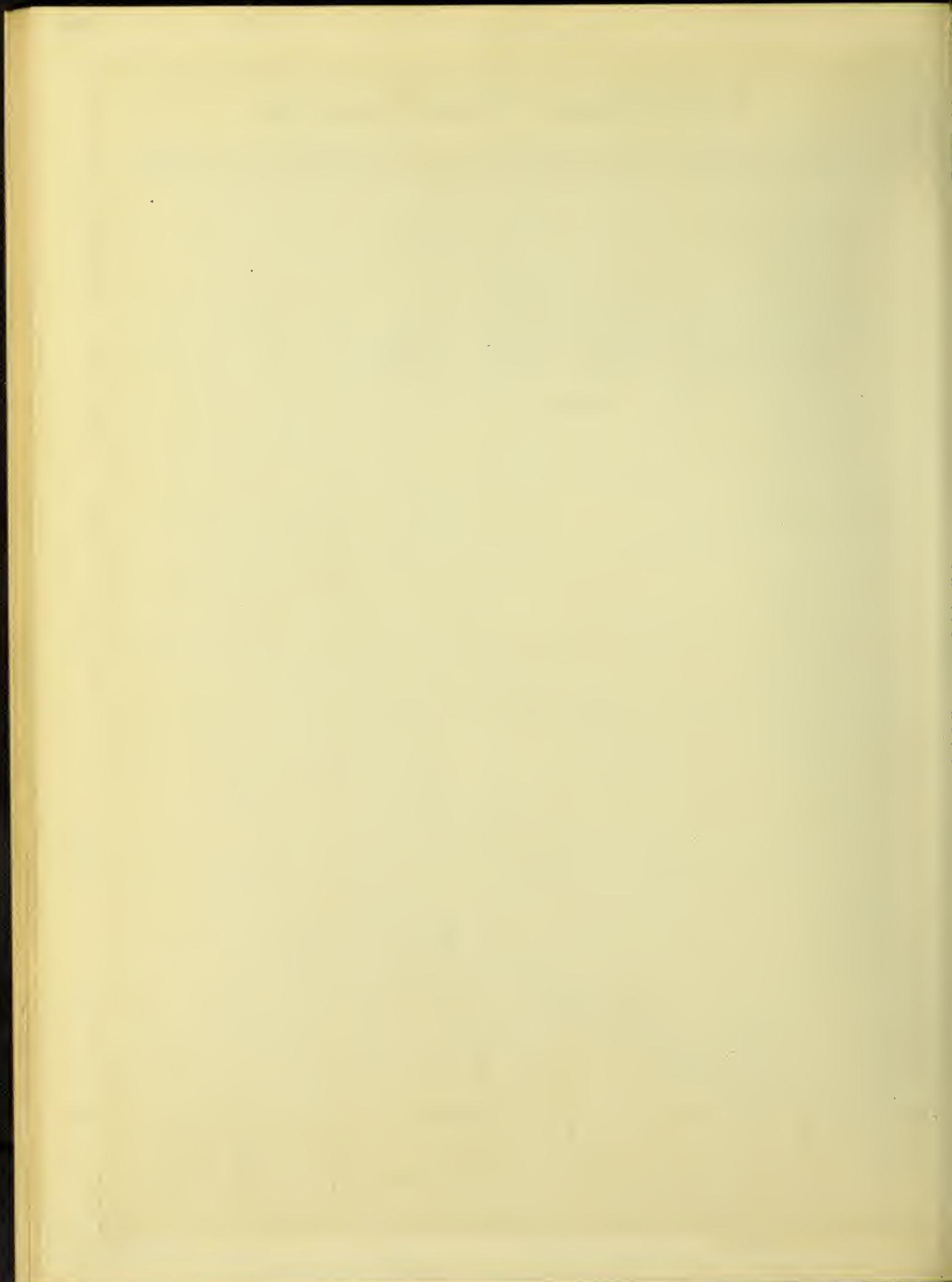
Plate VII shows the variation of slip and efficiency of the different motors. As might be expected the efficiency increases with the size of the motor, but is greater for loads as low as 15%, in the smaller sizes. The curves of slip show that it does not vary in a straight line but becomes greater as the full load is approached and rises rapidly after the machine is overloaded.



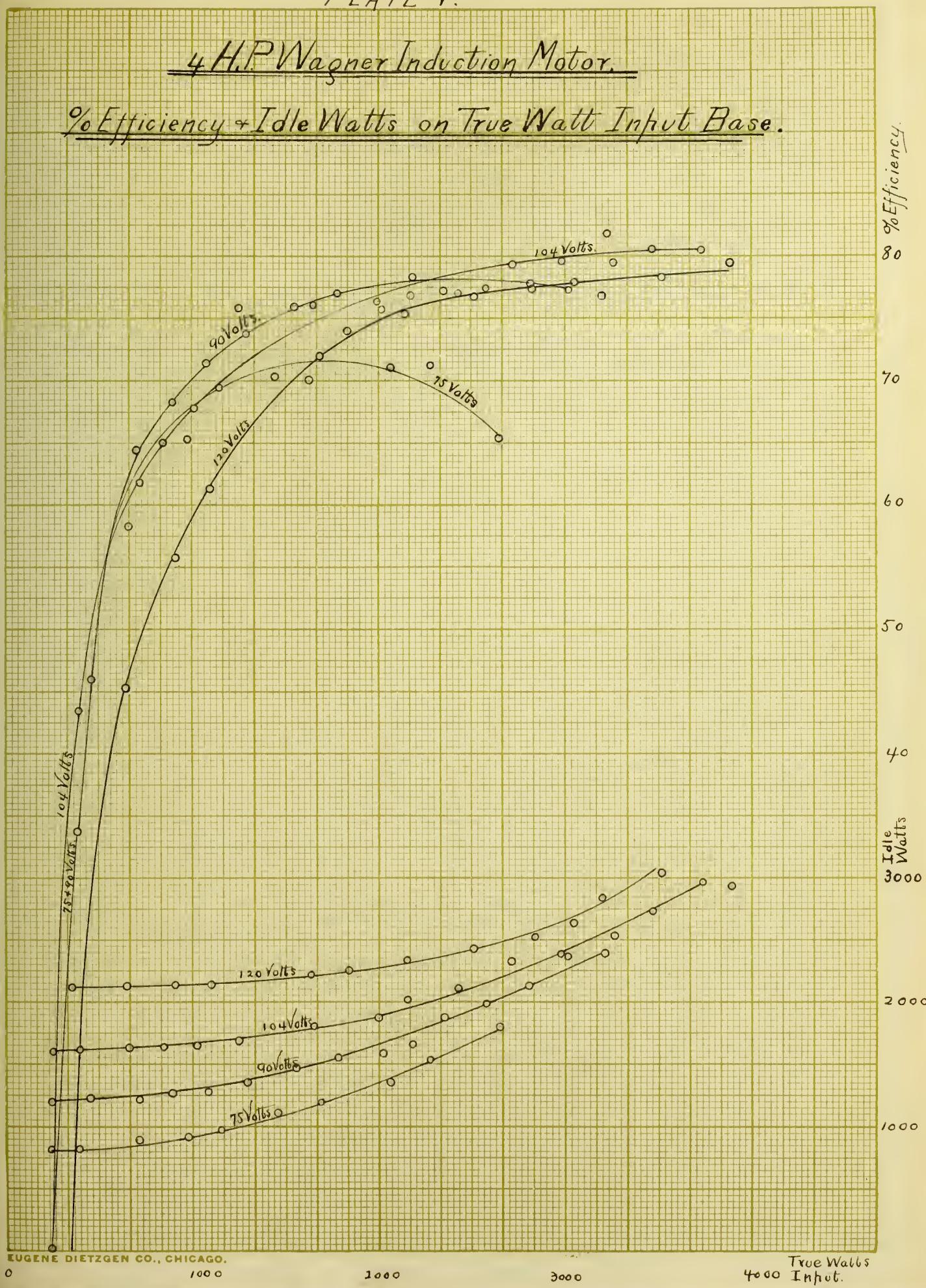
## 2 H.P. Wagner Induction Motor.

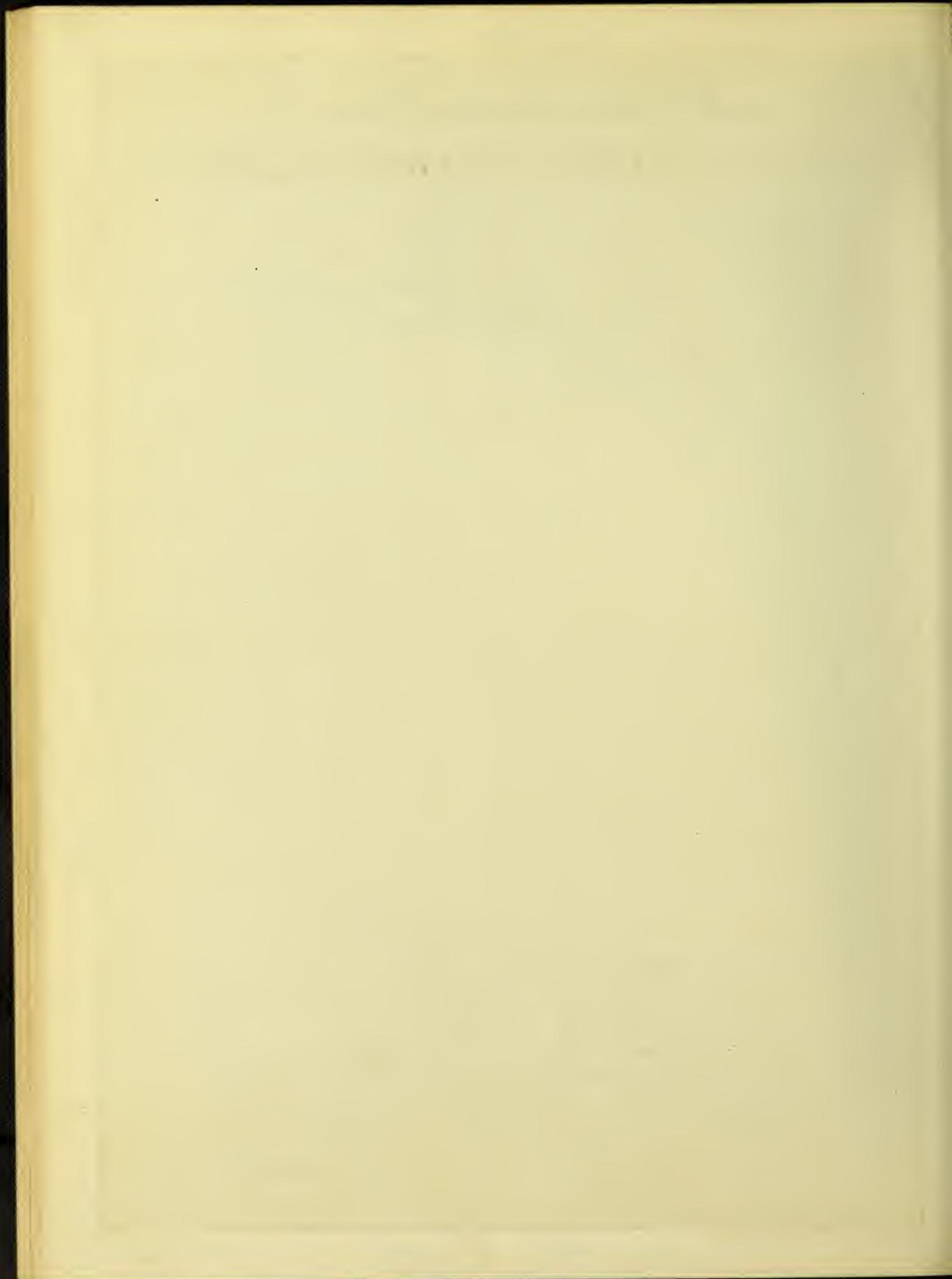
% Efficiency + Idle Watts on True Watt Input Base.

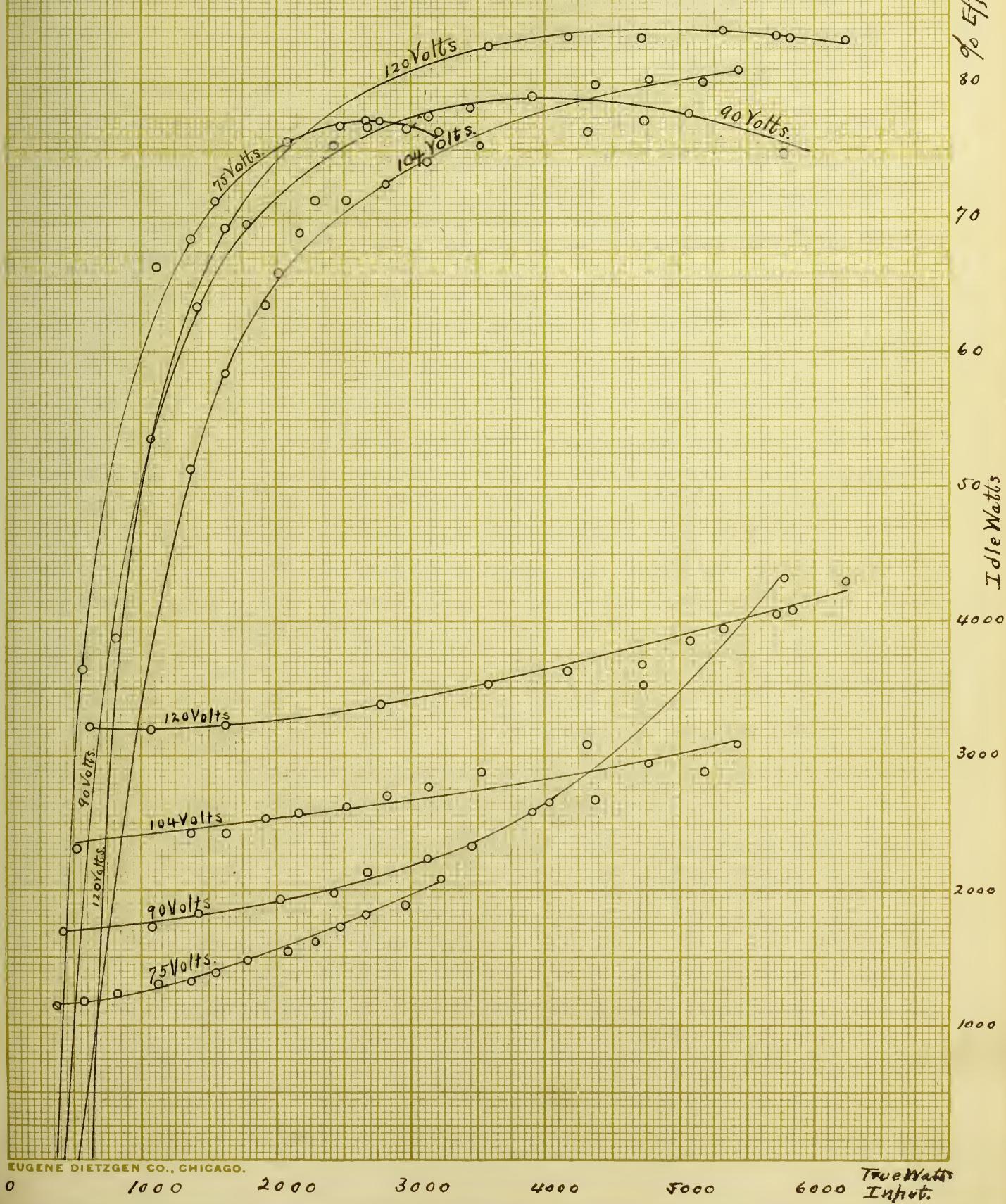


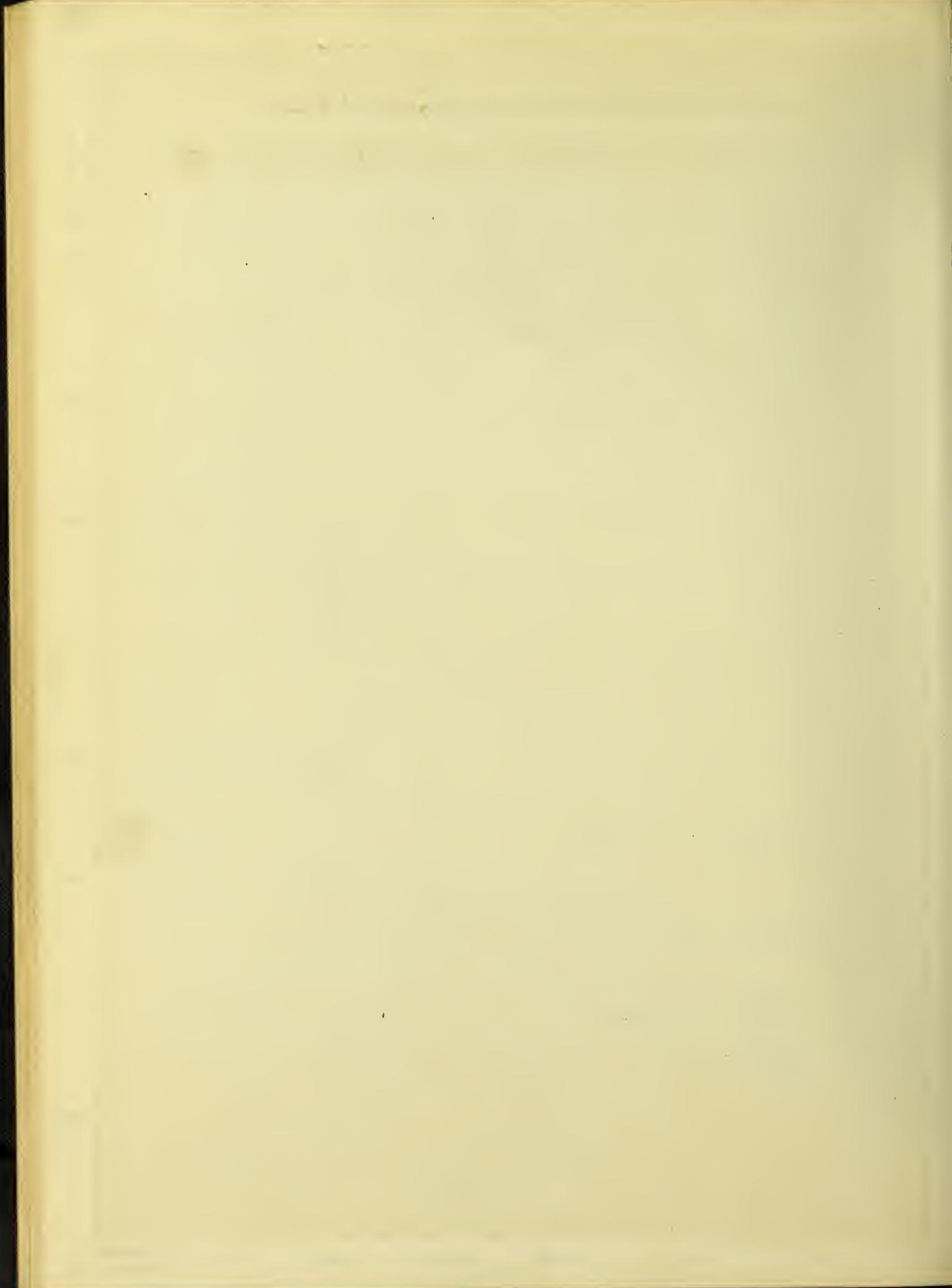


## PLATE V.

4 H.P. Wagner Induction Motor.% Efficiency & Idle Watts on True Watt Input Base.

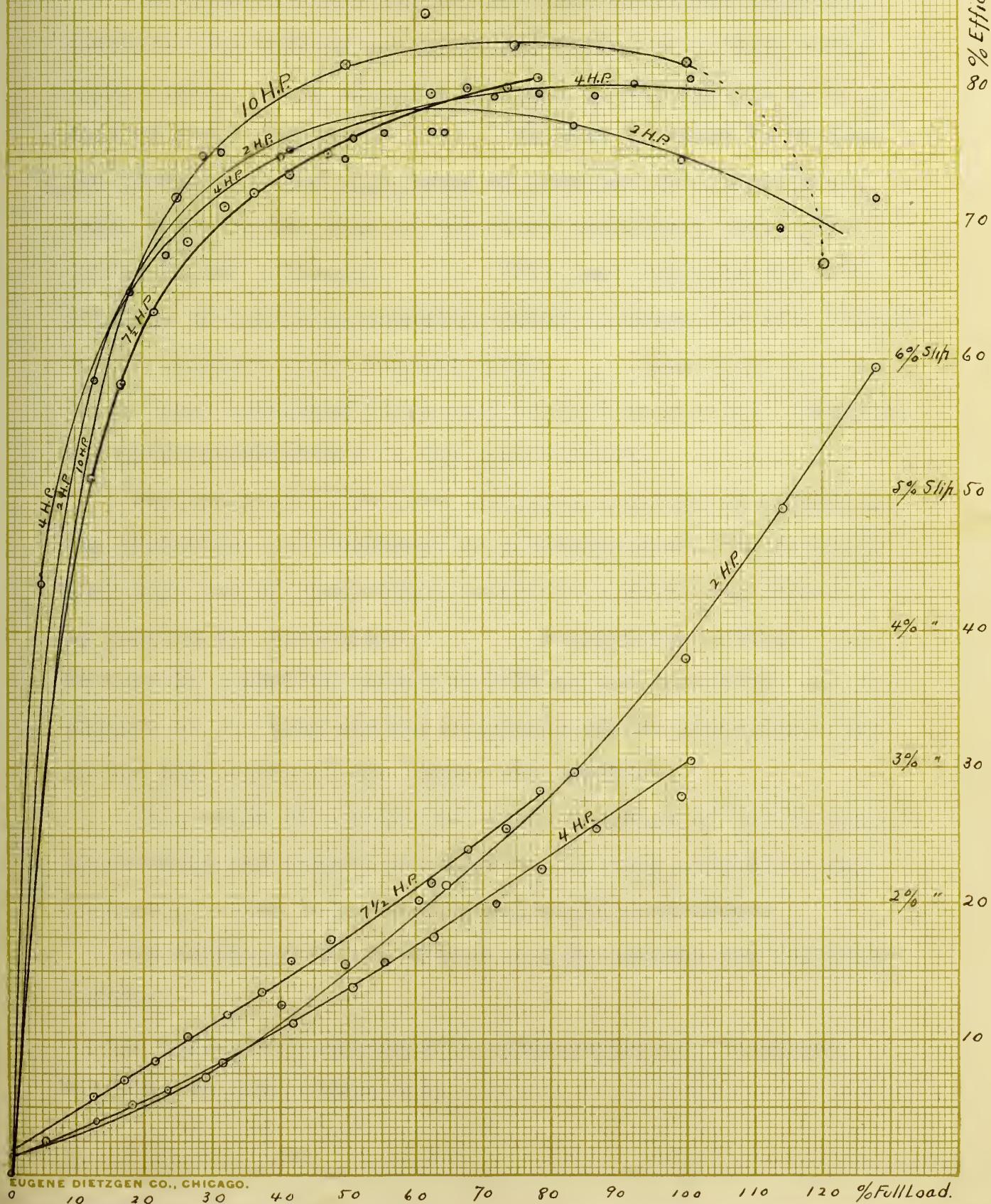


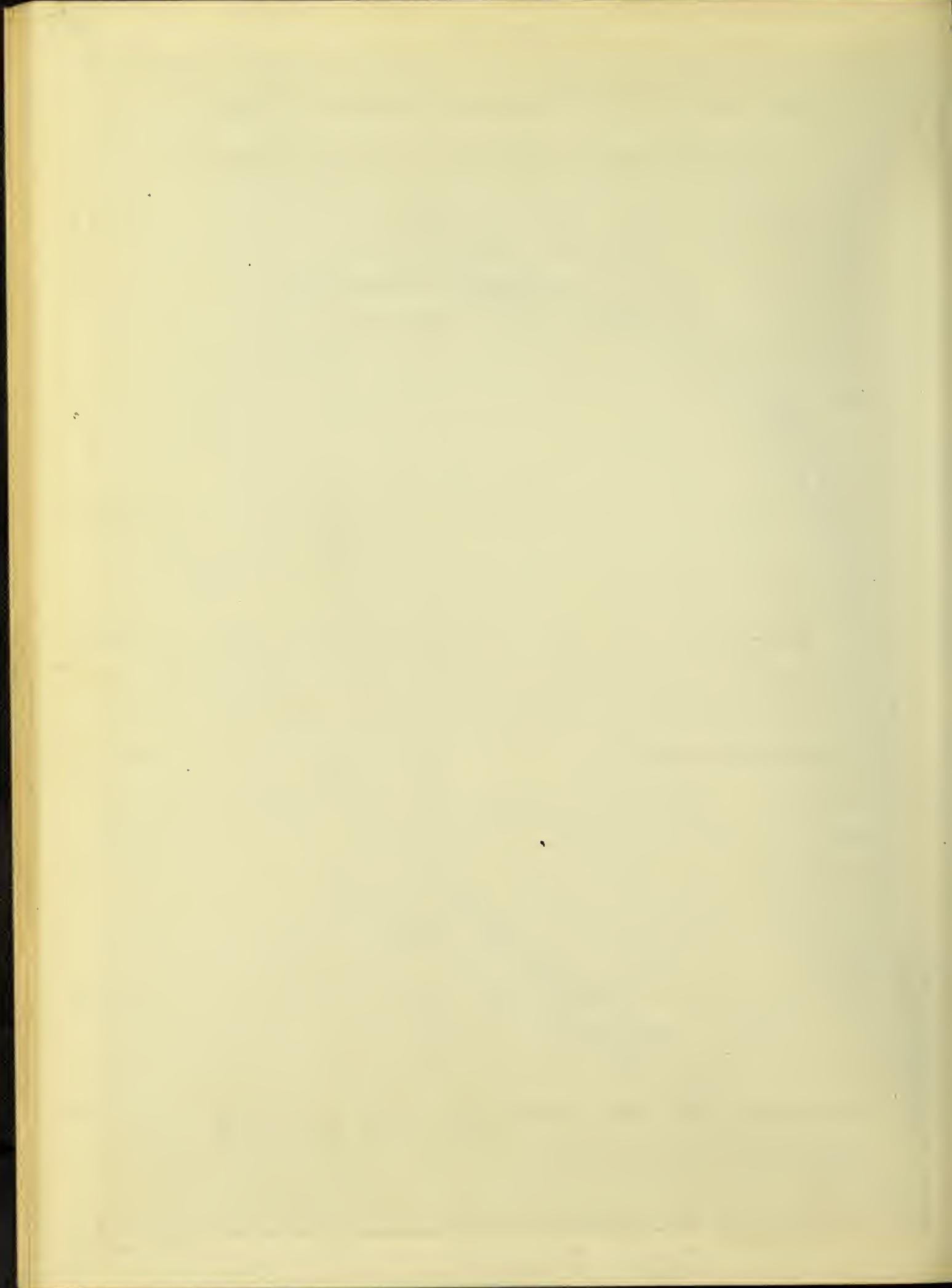
7 1/2 H.P. Wagner Induction Motor.% Efficiency & Idle Watts on True Watt Input Base.



2, 4, 7½ + 10 H.P. Wagner Induction Motors.

% Efficiency + Slip on % Load Base.





In Plate Vlll are plotted the idle watts and true efficiency of the various motors at 104 Volts, on a "true watts input" base, Plate IX shows the same curves plotted on a percent of full load base. In both of these is noticed the tendency of the idle watts to increase less rapidly at large loads as the size of the motor increases, just as they do for higher voltages. This fact suggests the possibility of having an induction motor in which the idle watts remain constant under varying loads. Such a motor would be of great advantage if it were desired to run both induction and synchronous motors in the same circuit.

Steimnetz and Rice have developed a method of balancing the resistance and reactance of a transmission line in which they make use of synchronous motors as a balancing capacity by varying the excitation. Synchronous motors could be used in a similar manner to balance the resistance and reactance of the line and the reactance of the induction motor if the idle watts of the latter are constant.

This would be a solution of the question of how to operate synchronous and induction motors in the same circuit or any load at any time to approach ideal ohmic conditions.

In looking over the curves we have noticed the following points;

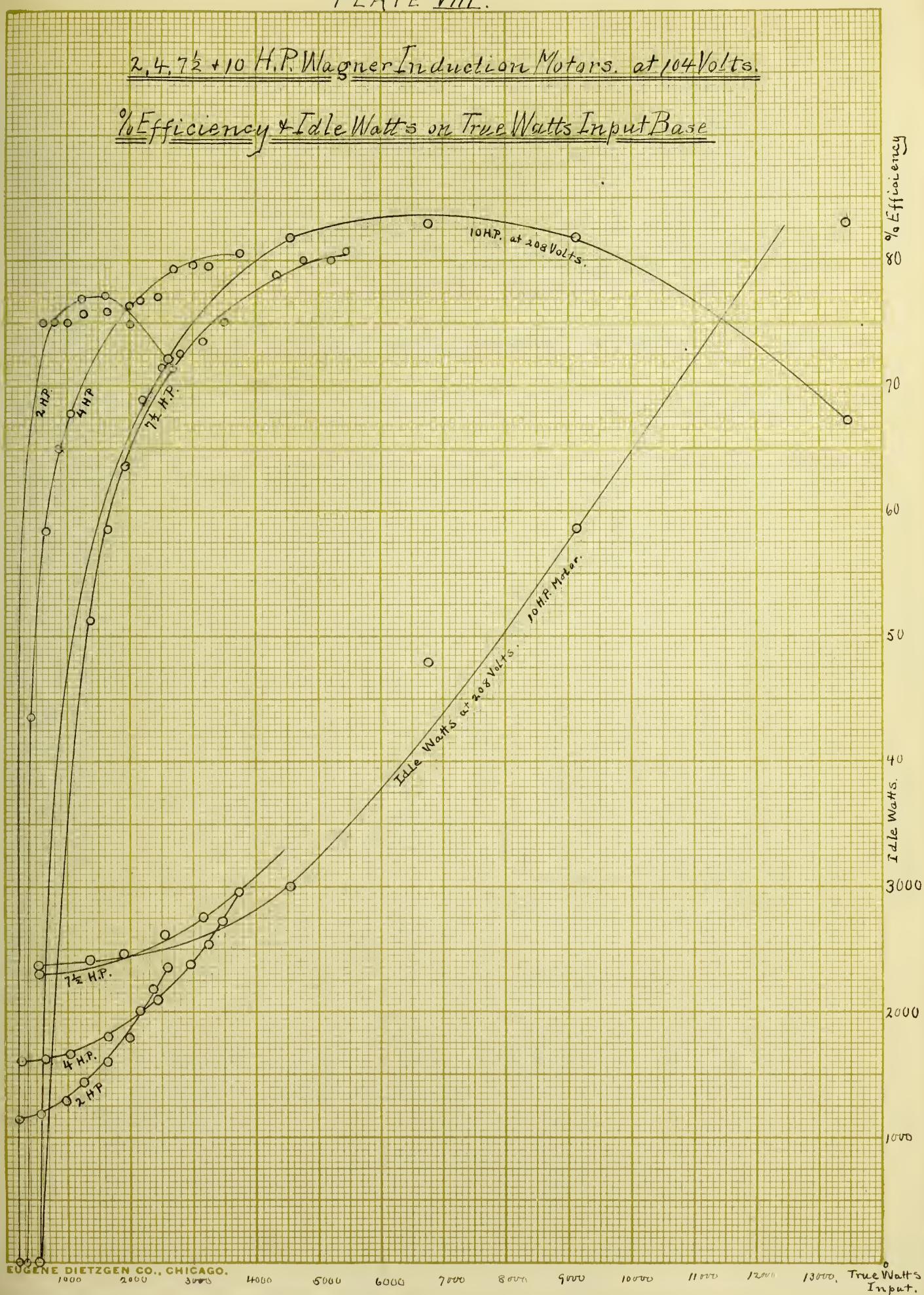
In two motors the maximum efficiency occurs at the highest voltage, in one it does not.

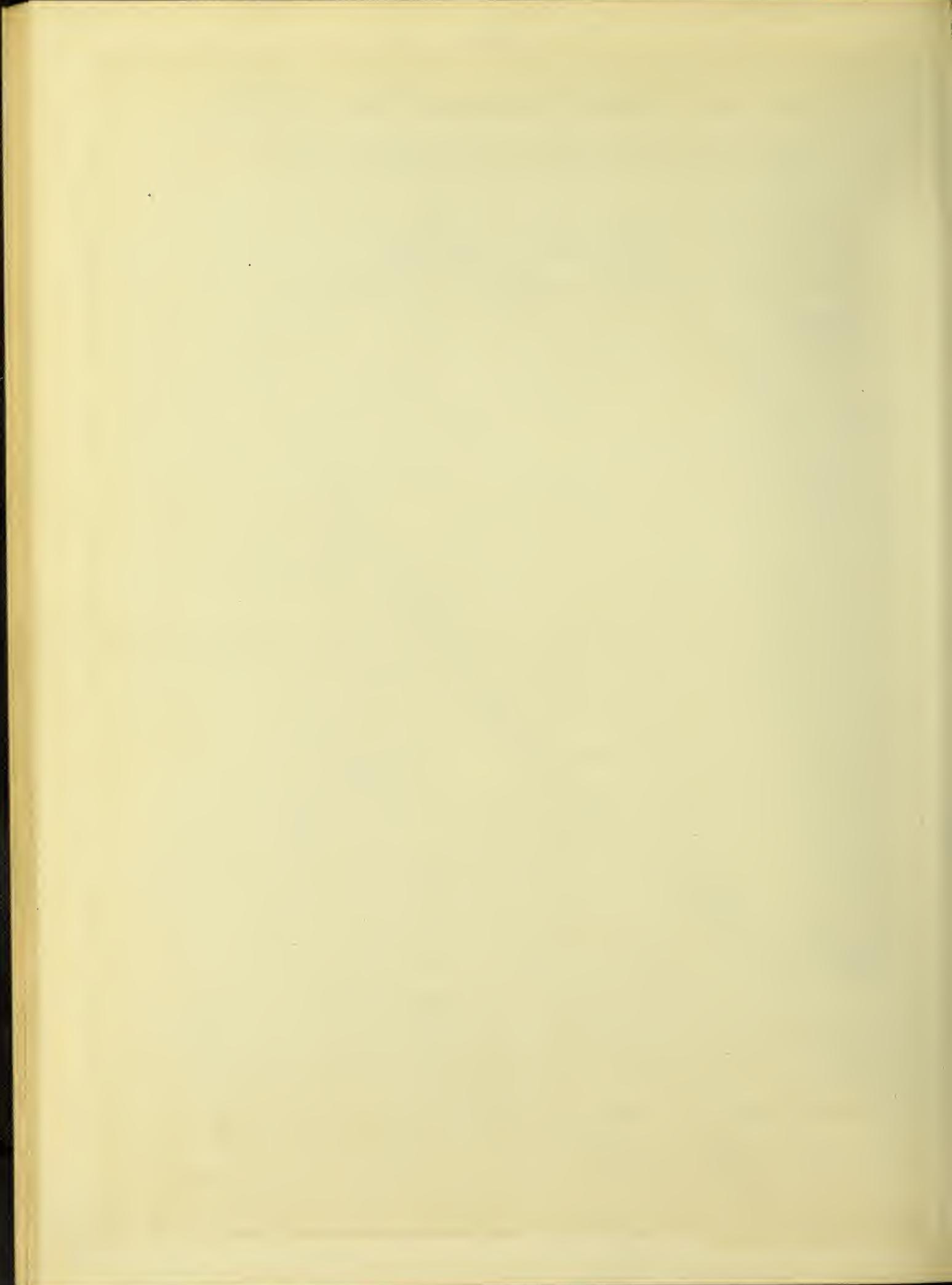


## PLATE VIII.

2, 4, 7½ + 10 H.P. Wagner Induction Motors. at 104 Volts.

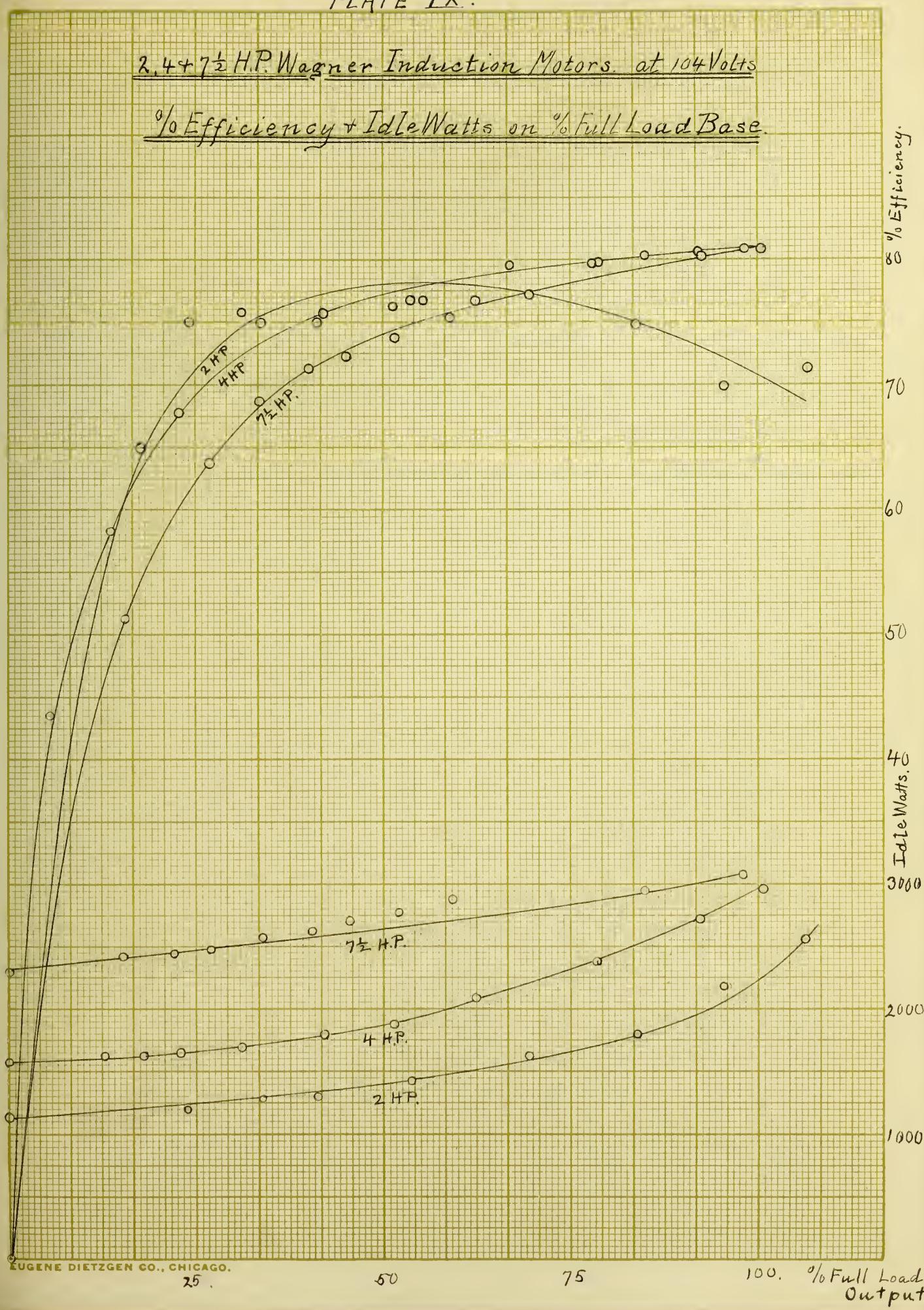
% Efficiency & Idle Watts on True Watts Input Base





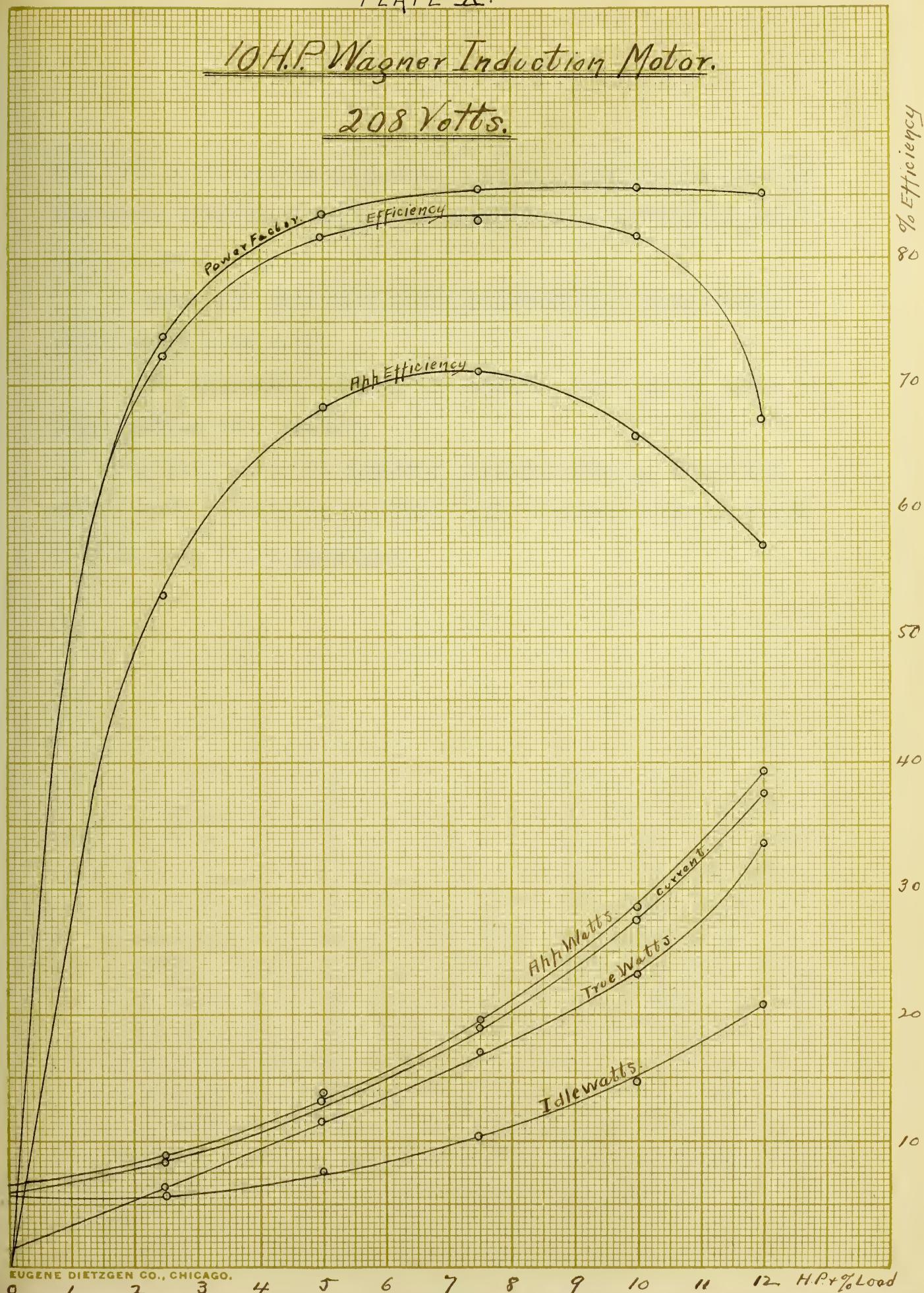
2, 4 & 7½ H.P. Wagner Induction Motors. at 104 Volts

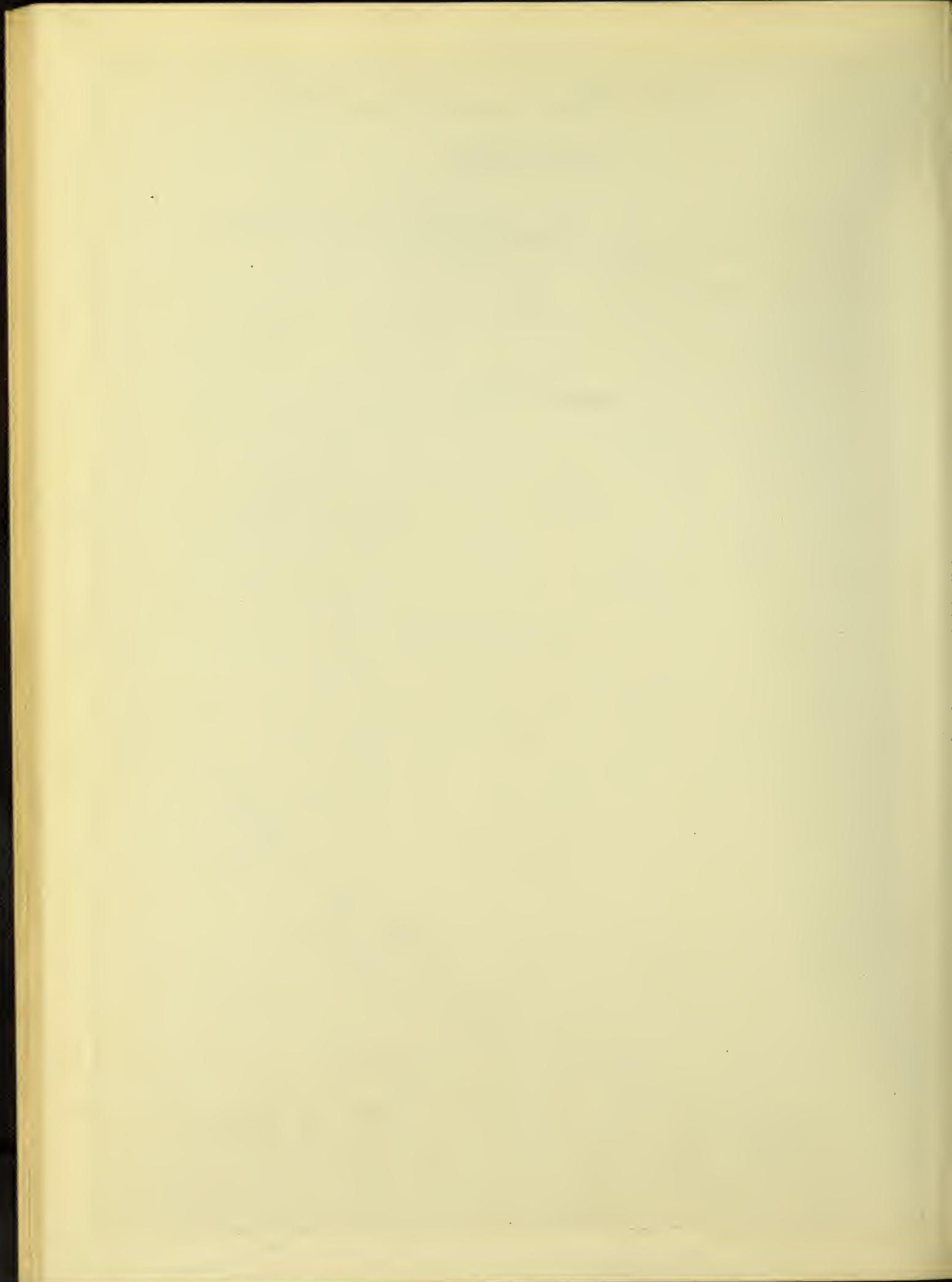
% Efficiency & Idle Watts on % Full Load Base.





## PLATE X.

10 H.P. Wagner Induction Motor.208 Volts.



The idle watts curves flatten out as the voltage and size of the motor increases but do not seem to ever approach a constant value.

In case the idle watts were constant the power factor would never bend over.

The lower the voltage the smaller the load at which the power factor is a maximum.

The slip curve is almost a straight line at first but curves more rapidly as the full load is approached and rises quickly when it is exceeded.



## THEORETICAL

As stated elsewhere in this thesis the method usually used in the theoretical consideration of the induction motor is the one in which the motor is considered as a transformer, having a movable secondary circuit. If now we let

$p$  = number of equal circuits on primary

$n$  = " " primary turns per circuit

and let the corresponding terms for the secondary be represented by the same symbols with the subscript "1" then

$\frac{n_p}{n'_p} = a$  = the ratio of total primary turns to total secondary turns.

It is preferable to reduce all secondary quantities to the primary system by the ratio of transformation "a"; since the number of secondary circuits and the number of turns per secondary circuit is unessential; then if  $E'_1$  is the secondary E. M. F per circuit,  $E_1 = a E'_1$  = secondary E.M.F. per circuit reduced to primary system. Similarly

$I_1 = \frac{I'_1}{a}$  = secondary current per circuit

$r_1 = a^2 r'_1$  = secondary resistance per circuit

$X_1 = a^2 X'_1$  = secondary reactance per circuit

$Z_1 = a^2 Z'_1$  = secondary impedance per circuit

all reduced to primary system

Let  $\Phi$  = total maximum flux of the magnetic field, per motor pole and  $N$  = frequency of primary impressed E. M. F.

Then  $E = \sqrt{2} \pi n N \Phi \times 10^{-8}$  is the effective electromotive force induced by the magnetic field per primary



circuit and  $E = -e$  where  $e = \sqrt{2} \gamma n N \Phi 10^{-8}$  may be considered as the active electromotive force of the motor and  $\Phi = f \phi$  in complex quantities time being counted from the moment where the flux  $\Phi$ , interlinked with both primary and secondary circuits passes through zero.

Since the secondary frequency is  $s/N$ , the secondary induced E. M. F. (reduced to primary system) is  $E_s = -s e$

While there are numerous formulae relating to the induction motor the ones most interesting to us were the formulae for torque and power and these were selected for comparing the theoretical and observed values.

The torque of any motor is dependent upon the number of armature conductors, the current flowing in them and the strength of the enveloping magnetic field and the sine of the angle between them. Therefore, in the induction motor if

$\frac{\Phi}{\sqrt{2}}$  = the effective magnetism developed in a single pole

$\frac{F_s}{\sqrt{2}}$  = the effective rotor magnet motive force and

$\sin(\phi_F)$  = the sine of the angle between them, and  $T'$  be the torque we have

$$T' = \frac{\Phi F_s}{2} \sin(\phi_F)$$

also if  $n_s$  = the number of turns

$I_s$  = current per circuit and

$\mu$  = the number of armature circuits

we have for the value of the armature magnet motive force

$$F_s = \frac{\mu n_s I_s}{\sqrt{2}}$$



and substituting this in the above formula gives

$$T' = \frac{\phi p n_i I_s \sin(\phi f_i)}{2\sqrt{2}}$$

and since there are "d" poles the total torque  $T$  becomes -

$$T = d \frac{\phi p n_i I_s \sin(\phi f_i)}{2\sqrt{2}}$$

The electromotive force  $E$ , induced in the rotor is  $90^\circ$  behind the inducing magnetism hence it reaches a maximum when the inducing magnetism is zero. There is also a lag of the current in the rotor due to the impedance of the rotor coils and if the lag of this be  $w$ , the total lag of the current in the rotor behind the field or stator magnetism is  $(90^\circ + w)$ .

The sine of this is equal to cosine  $w$ , and the cosine  $w$ , is  $\frac{r_i}{\sqrt{r_i^2 + s^2 x_i^2}}$ ; since the tangent of the lag angle equals the reactance over the resistance or  $\frac{s x_i}{r_i}$  and  $\cos = \frac{1}{\sqrt{1 + \tan^2}}$ .

The current in the rotor coils is equal to the electromotive force induced in the rotor windings divided by the impedance. Since the frequency of the E. M. F. of the rotor depends on the slip, the impedance must also depend on the slip and, therefore, the slip must be a factor of the expression for rotor current; hence when reduced to primary system we have current in rotor

$$I_r = \frac{e s}{\sqrt{r_i^2 + s^2 x_i^2}}$$

since "e" is the electromotive force induced per turn by the



mutual magnetic flux the total "e" must be equal to the number of turns in series per circuit multiplied by the flux and the frequency. If

$n_s$  = number of turns in series

$\phi$  = the flux and

$N$  = the frequency

we have for one circuit

$$e = \frac{\sqrt{2} \pi n_s \phi N}{10^8}$$

$$\text{or } \phi = \frac{e \cdot 10^8}{\sqrt{2} \pi N n_s} \text{ therefore}$$

taking the equation for torque

$$T = \frac{d \phi \rho n_s I_s \sin(\phi f_s)}{2 \sqrt{2}}$$

$$\text{or } T = \frac{d \phi \rho n_s I_s \cos \omega}{2 \sqrt{2}}$$

and substituting we have

$$T = \frac{d \rho r_s s e^2 \cdot 10^8}{4 \pi N (r_s^2 + s^2 x_s^2)}$$

by means of which we can determine the torque if we know the value of "e"

Before proceeding to evaluate "e" let us consider what the output of the motor will be.

At a unit radius the circumference of a circle is  $2\pi$  and since the speed of an induction motor =  $\frac{2 N(1-s)}{d}$  where  $N$  = frequency and  $d$  = the number of poles  $\times$   $s$  the slip; the linear distance passed over by a point on the circumference in one second is  $\frac{4\pi N(1-s)}{d}$  and if  $T$  is the torque, the output of the motor will be  $\frac{T 4\pi N(1-s)}{d}$  or substituting for  $T$  the value already found we have the output or power

$$P = \left[ \frac{4\pi N(1-s)}{d} \right] \left[ \frac{d \rho r_s s e^2 \cdot 10^8}{4 \pi N (r_s^2 + s^2 x_s^2)} \right]$$



which reduces to  $P = \frac{\mu n s e^2 (1-s) 10^8}{r^2 + s^2 x^2}$

We can now determine power and torque if we can evaluate "e"

As the rotor revolves there is a back E. M. F. induced in the stator coils by the cutting of them by the flux due to the rotor current, and since "e" is defined as the electromotive force induced per turn by the mutual magnetic flux we have  $-E_B = e$ . Now the applied electromotive force at the terminals must be sufficient to overcome this back E. M. F. and also to overcome the impedance drop, hence the applied E. M. F.

$$E_o = E_B + E_Z$$

or  $E_o = e + E_Z$

$E_Z$  = the E. M. F. consumed by the primary impedance and is therefore  $= IZ$  but  $I$  is composed of two parts, an exciting current  $I_o = eY$  where  $Y$  is the admittance of the primary, and a component corresponding to the secondary current or

$$I' = \frac{se}{r - jsx}$$

hence the total primary current  $= I = I' + I_o$

$$= e \left[ \frac{s}{r - jsx} + (g + jb) \right] \quad \text{since } Y \text{ the admittance} = (g + jb)$$

substituting these in  $E_Z = Z I$  we have

$$E_Z = Z e \left[ \frac{s}{r - jsx} + (g + jb) \right] = e(r - jx) \left[ \frac{s}{r - jsx} + (g + jb) \right]$$

and since  $E_o = e + E_Z$  we have

$$E_o = e \left[ 1 + \frac{s(r - jx)}{r - jsx} + (r - jx)(g + jb) \right]$$

or



approximately  $E_o = e \left[ 1 + \frac{s(r-jx)}{r_j - j s x_j} \right]$  Solving for e we get

$$e = E_o \sqrt{\frac{r_j^2 + s^2 x_j^2}{(r_j + s r)^2 + s^2 (x_j + x)^2}}$$

in real values, which are obtained by taking the square root of the sums of the squares of the imaginary values, and substituting this value of "e" in the formulae for torque and power we have

$$T = \frac{d \rho r_j E_o^2 s}{4 \pi N (r_j + s r)^2 + s^2 (x_j + x)^2}$$

$$P = \frac{\rho r_j E_o^2 s (1-s)}{(r_j + s r)^2 + s^2 (x_j + x)^2}$$

the following off in. This was probably the first group of birds to  
arrive in the region. They had not been seen until the middle of October and the  
earliest date of migration is not known. We will have to wait until the  
beginning of November to see if any more birds arrive.

## MECHANICAL &amp; ELECTRICAL DATA ON WAGNER INDUCTION MOTORS.

Manufacturers No.	2 H.P.	4 H.P.	7½ H.P.	10 H.P.
	AC. 1	AC 2a	AC 3½	AC. 5.
Serial No.	581	719	807	868
Type of Machine	Single Ph.	Sim. Ph.	Sim. Ph.	Sim. Ph.
Number of Poles	4	4	4	4
Capacity H.P.	2	4	7½	10.
Speed R.p.m. no load	1800	1800	1800	1800.
Speed R.p.m. full load	1718	1747	1740.	1725
Frequency in cycles	60	60.	60	60.
Volts, normal	104	104	104	104
Volts, no load	"	"	"	"
Volts full load	97	80	-	-
Starting current full load	24	44	78	100.
Current - no load -Amp.	16	15	21	33.

## A Rotor.

Peripheral velocity - ft per sec.	64.3	64.2	86.08	86.08
Diameter over all	8.19"	8.17"	10.96"	10.96"
Diam. of core, internal	4.07"	4.05"	4.96"	4.96"
Length of core over all	3.4"	3.4"	4.75"	4.75"
Thickness of Laminæ	26 B+5	26 B+5	26 B+5	26 B+5
Width of slots	$\frac{9}{32}$ "	$\frac{9}{32}$ "	$\frac{13}{32}$ "	$\frac{9}{32}$ "
Depth of slots	1.06"	1.06"	1.12"	1.12"
Number of Slots	47	47	65	65
Width of tooth, minimum	$\frac{11}{64}$ "	$\frac{11}{64}$ "	$\frac{13}{64}$ "	$\frac{13}{64}$ "
" " " at root	$\frac{11}{64}$ "	$\frac{11}{64}$ "	$\frac{13}{64}$ "	$\frac{13}{64}$ "
" " " at surface	$\frac{7}{16}$ "	$\frac{7}{16}$ "	$\frac{7}{16}$ "	$\frac{7}{16}$ "



	2 HP	4 HP	7½ HP	10 HP
	#12	#12	#11	#11
	Fuller	Board		
Size of wire				
Insulation				
Number of coils, per slot	4	4	4	4
" " conductors, per slot	16	16	8	8
" " turns, per coil	2	2	1	1
" " wires in multiple	2	2	2	2
Air gap	.0215	.021	.022	
Resistance Brush to Brush.	.078			

### B Stator

External diameter	12.98	12.96	16.5	
Resistance	.182			
Internal "	.155			
Impedance	8.23	8.24	11.	
Length of core	3.4	3.4	4.75	4.75
Thickness of laminæ	#26	#26	#26	#26
Number of slots	40	40	56	56
Depth of slots	1.25	1.25	1.25	1.25
Width of slots	.2	.2	.2	.2
Insulation			Fuller Board + Duck	
Width of tooth, minimum	0.26	.26		
" " " at root	.46	.46		
" " " at surface	.52	.52		
Polar embrace	360°	360°	360°	360°
Length of polar arc	90°	90°	90°	90°
Size of wire	#11	#13	#11.	
Number of turns per slot	21	12½	14½	
" " " " pole	210	125	145	
" " wires " slot	21	25	14½	
" " " " multiple	1	2	1	
Loop after Turn No.	18	11	12½	
Number of Poles in Series	2	2	1	1

1960-1961  
1961-1962

1962-1963  
1963-1964

1964-1965  
1965-1966

1966-1967  
1967-1968

1968-1969  
1969-1970

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1995-1996

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1997-1998

1998-1999  
1999-2000

2000-2001  
2001-2002

2002-2003  
2003-2004

2004-2005  
2005-2006

2006-2007  
2007-2008

2008-2009  
2009-2010

2010-2011  
2011-2012

2012-2013  
2013-2014

2014-2015  
2015-2016

	2 P	4	7 1/2	10
C Commutator.	7 13/16	7 13/16	10.5	10.5
Diameter, External				
" Internal	3 5/8	3 5/8	5.	5
Length - radial	2.3/32	2 3/32	2.75	2.75
" axial active	1.5	1.5	2 1/16	2 1/16
Maximum width of segment	7/32	7/32	15/64	15/64
Minimum " " "	3/32	3/32	6/64	6/64
Thickness of mica between segments	.04	.04	1/32	1/32
Number of segments	93	93	129.	129
" " " per slot	93/47	93/47	129/65	129/65
" " " covered by brushes	2	1	1	1
" " - - - wires per segment	4	4	4	4

## D. Brushes.

Number	2	4	4	4
Length radial	1.5	1.5	2.06	2.06
Width maximum	7/32	9/32	9/32	9/32
" minimum	3/32	5/32	5/32	5/32
Area of contact	.23"	.33"	.44"	.44"
Type of brush	Carbon	—	—	—

## Electrical Data

## Rotor

Resistance, cold, Brush to Brush.	.078
--------------------------------------	------



2 H.P. Wagner Induction Motor.

Volts Constant at 75.

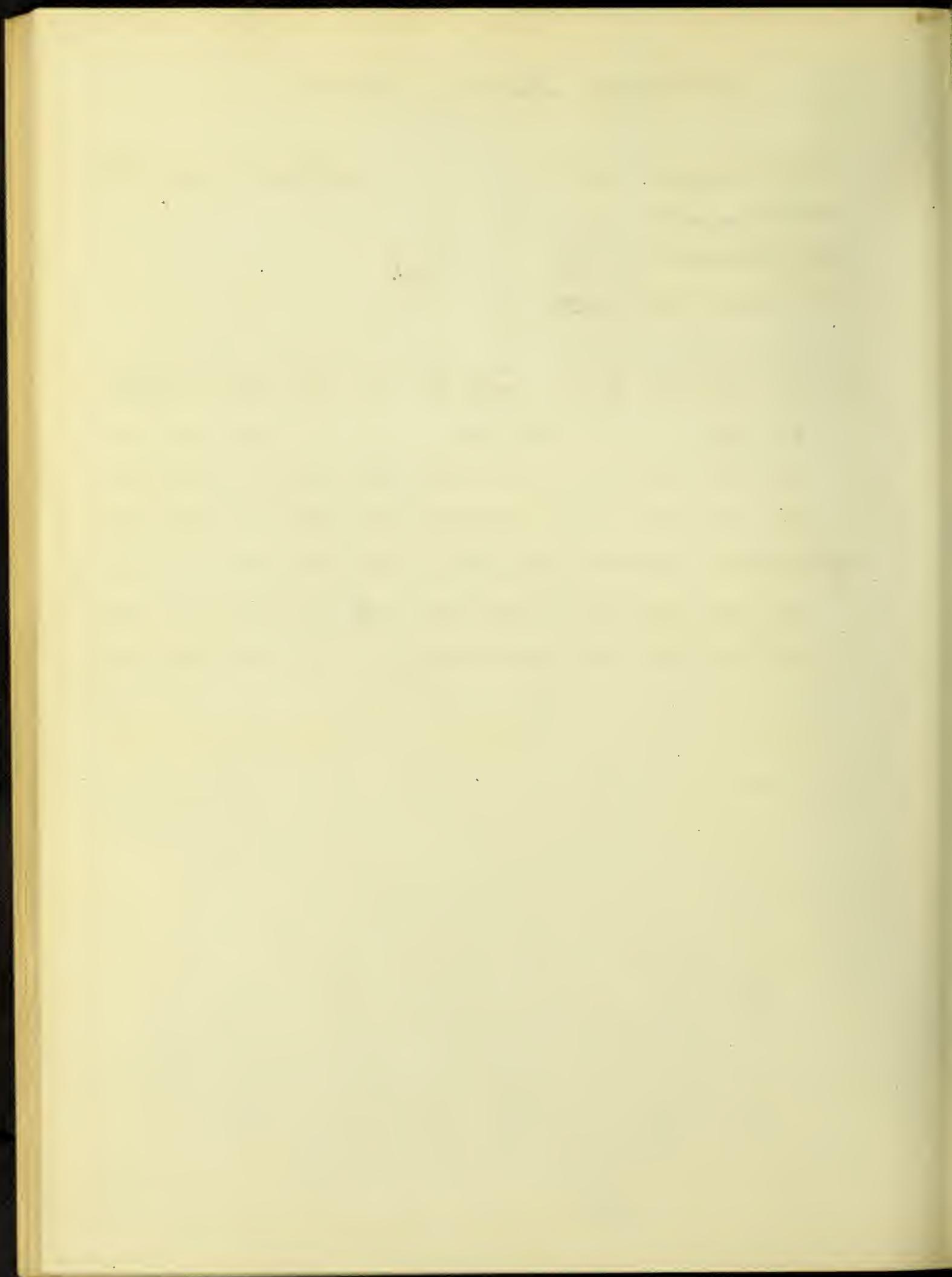
Speed 1760 R.P.M.

A.C. Ammeter 13457.

A.C. Voltmeter 857.

A.C. Wattmeter 775.

No	Amp	True Watts	Pull in Pounds	Slip R.P.M.	Slip %	Amp	H.P.	True Eff	Amp Eff	Power Factor	Induc Factor	Idle Watts.
1	8.4	165	0	8	4.54	630	0	0	0	.262	.965	607
2	10.9	435	2.25	28	1.59	818	.371	636	.339	.532	.847	693
3	14.1	675	4.03	46	2.61	1058	.658	.728	.564	.638	.769	814
4	19.8	1055	6.25	80	4.54	1484	1.00	.708	.503	.712	.702	1042
5	24.5	1305	7.75	124	7.05	1838	1.27	.724	.514	.710	.704	1293
6	28.1	1455	8.93	150	8.52	2108	1.437	.737	.508	.691	.722	1545



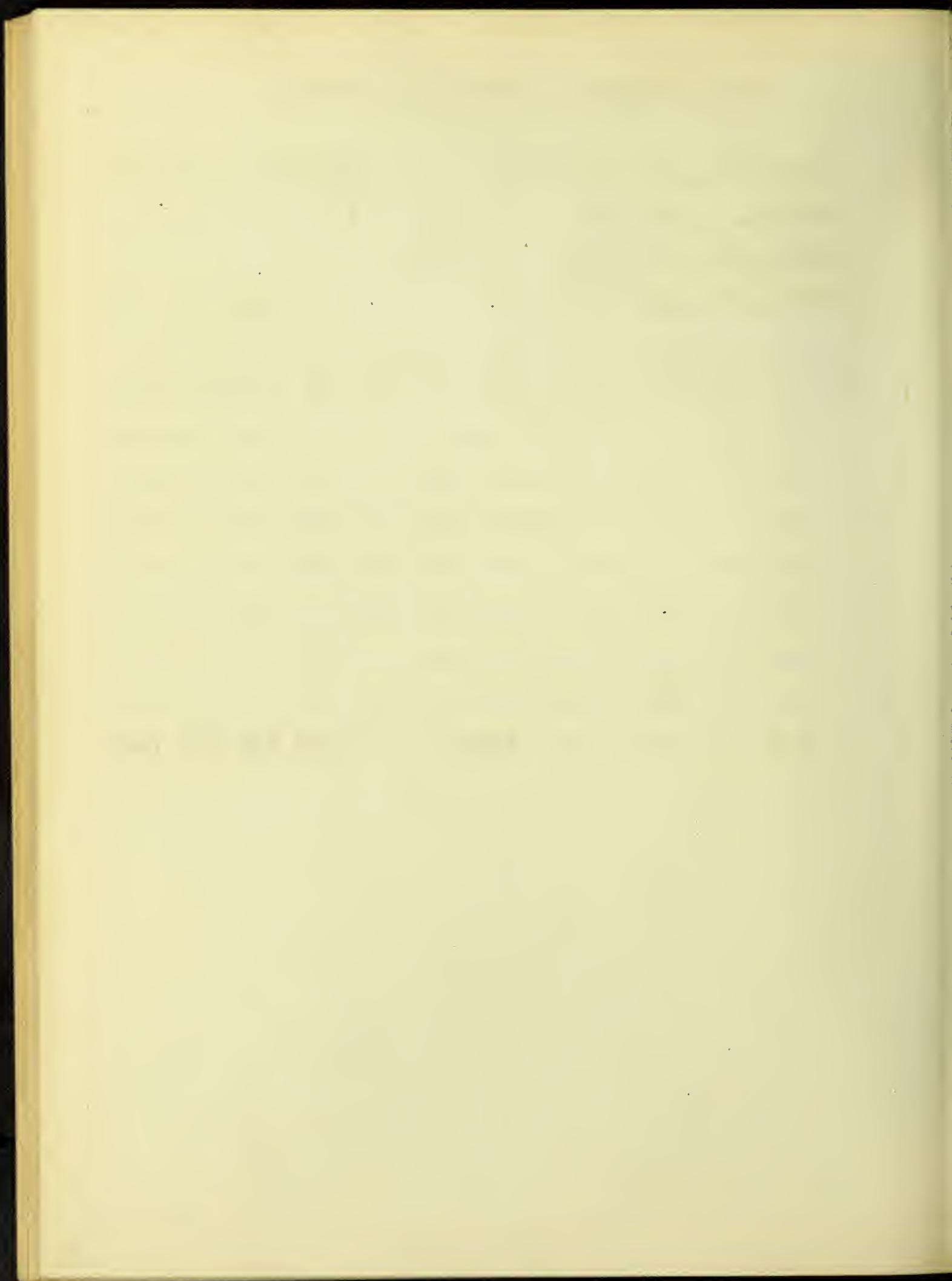
25 H.P. Wagner Induction Motor.

Volts constant at 90  
A.C. Ammeter 13457  
A.C. Voltmeter 857  
A.C. Wattmeter 775

Speed 1760 R.P.M.

May 26 1900

No	Amp	True Watts	Pull in Pounds	Slip RPM	Slip %	Aph Watts	H.P.	True Eff	Aph Eff	Power Factor	Induc Factor	Idle Watts
1	9.6	185	0	6	.341	.864	0	0	0	.214	.977	844
2	11.8	515	2.95	24	1.36	1061	.488	.707	.343	.485	.874	927
3	141	755	4.53	34	1.96	1268	.745	.735	.438	.596	.802	1017
4	16.3	985	6.01	46	2.61	1467	.982	.743	.499	.671	.741	1088
5	19.4	1215	7.69	62	3.52	1745	1.24	.764	.532	.696	.718	1253
6	20.9	1325	8.32	70	3.97	1880	1.34	.755	.533	.705	.709	1333
7	23.5	1505	9.44	84	4.77	2115	1.505	.746	.532	.712	.702	1485
8	30.4	1965	11.44	120	6.82	2735	1.79	.679	.488	.719	.695	1900



2.5 H.P. Wagner Induction Motor.

Volts Constant at 104

Speed 1760 R.P.M.

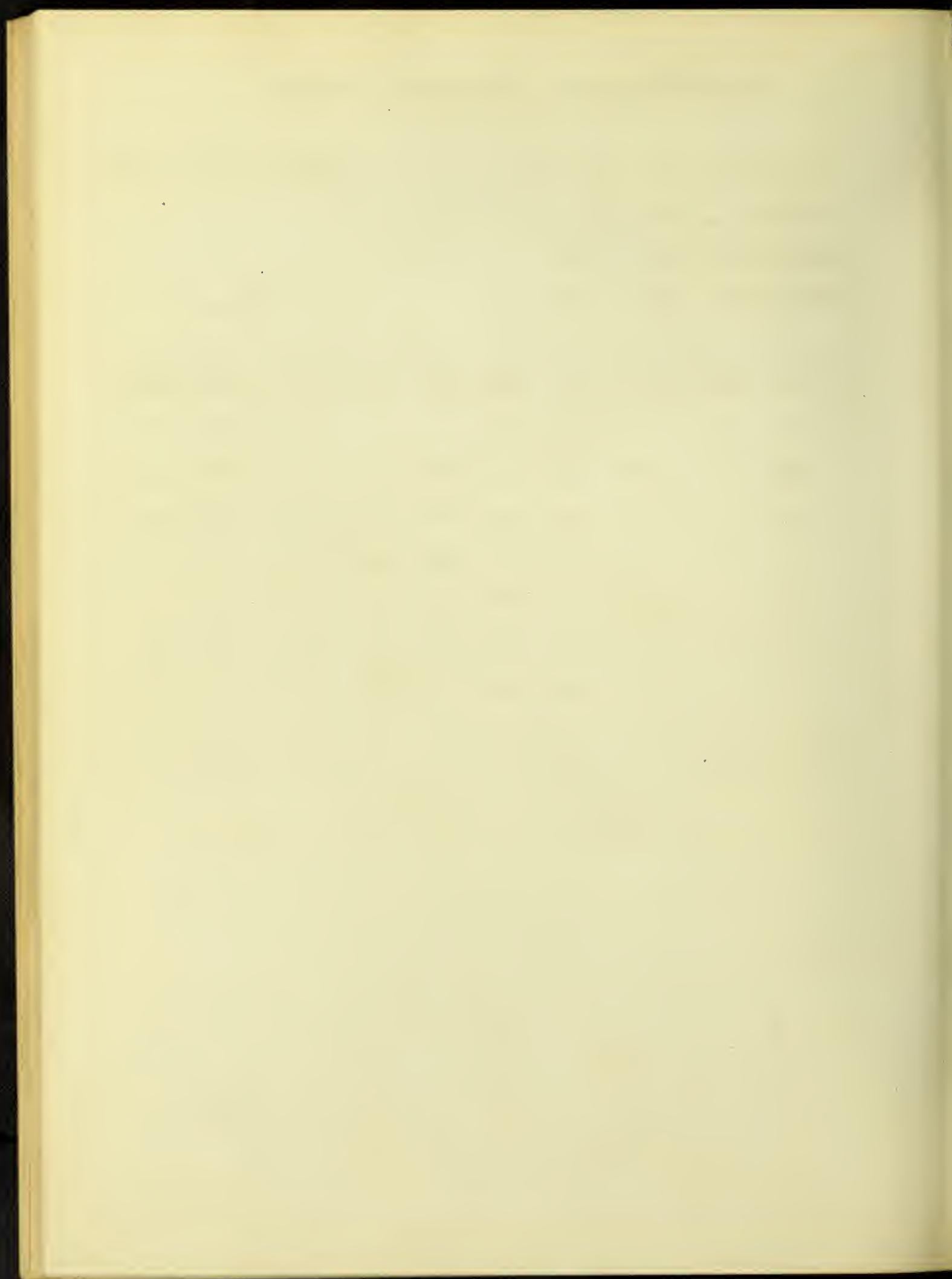
A.C. Ammeter 13457

A.C. Voltmeter 857

A.C. Wattmeter 775

May 26, 1900.

No	Amp <sub>h</sub>	True Watts	Pull in Pounds	Slip R.P.M.	Slip %	Amp <sub>h</sub> Watts	H.P.	True Eff.	Amp <sub>h</sub> Eff.	Power Factor	Induc Factor	Idle Watts
1	11.1	205	0	447	.254	1155	0	0	0	.775	.984	1134
2	12.8	575	3.2	16.	.742	1330	.58	.75	.376	.432	.900	1196
3	14.4	805	4.9	27	.125	1497	.808	.95	.40	.537	.843	1263
4	15.7	995	6.08	34.	.157	1632	.99	.749	.456	.608	.793	1293
5	18.3	1255	7.94	46.	.213	1902	1.29	.767	.506	.660	.752	1430
6	21.9	1615	10.37	64	.296	2275	1.67	.772	.548	.710	.704	1602
7	26.4	2005	12.62	82	.380	2744	2.01	.748	.547	.7315	.682	1800
8	30.7	2345	14.5	106	.491	3215	2.28	.696	.529	.7310	.683	2192
9	35.3	2675	16.5	128	.594	3700	2.56	.714	.516	.723	.689	2540



2 HP. Wagner Induction Motor.

Volts constant at 120

Speed 1760 RPM.

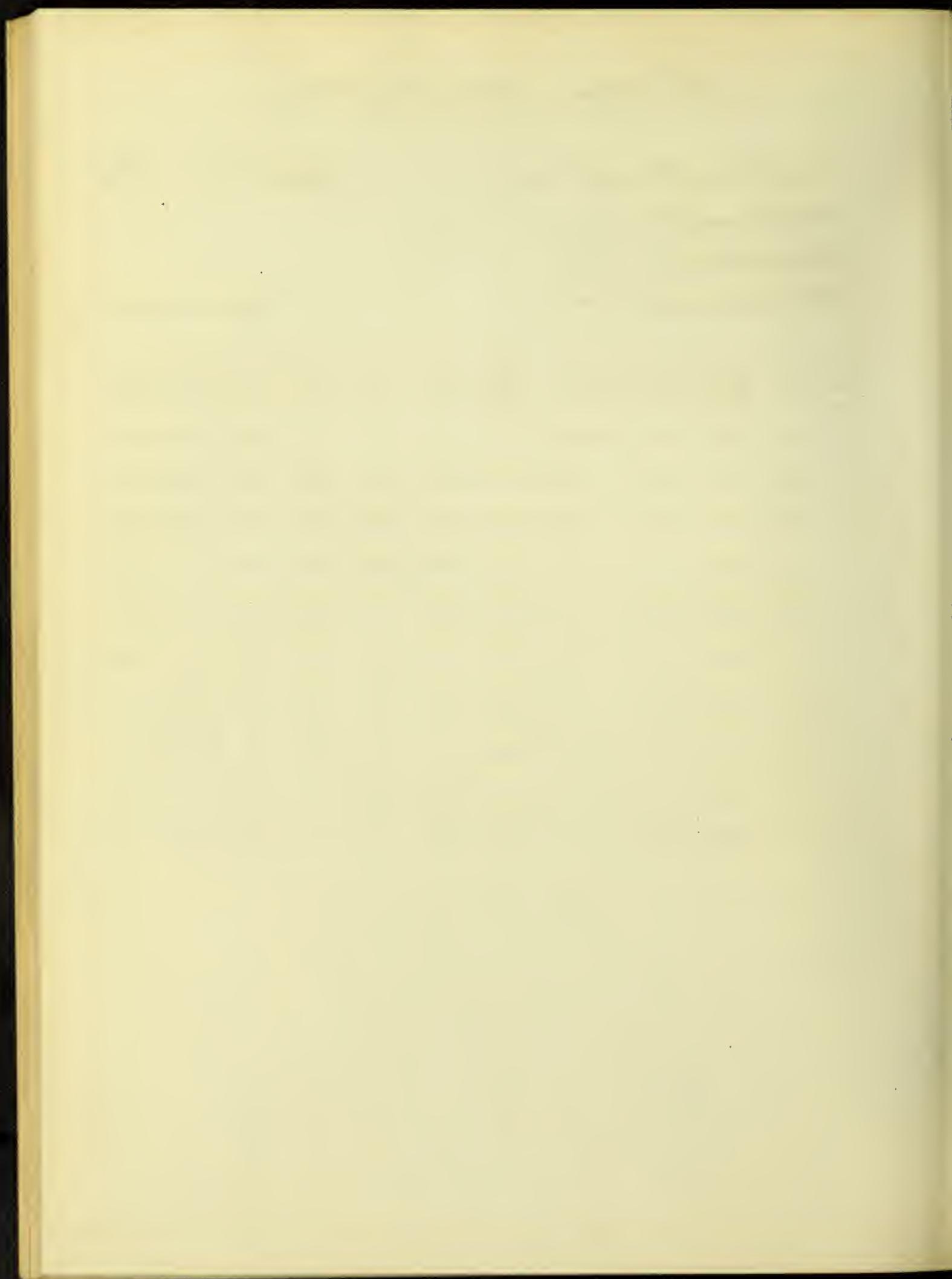
AC Ammeter 134.57

AC Voltmeter 857

AC Wattmeter 775

May 26 1900.

No	Amh	True Watts	Pull in Pounds	Slip RPM.	Slip %	Amh Watts	HP	True Eff	Amh Eff	Power Factor	Induc Factor	Idle Watts
1	12.7	255	0	3.66	.208	1573	0	0	0	.167	.986	1502
2	14.5	725	3.95	17.	.966	1740	.656	.674	.781	.416	.909	1582
3	16.7	1135	6.89	28.	.159	2005	1.135	.746	.422	.566	.824	1652
4	20.2	1595	10.19	44.	.2.5	2425	1.663	.778	.511	.658	.752	1822
5	23.4	1985	12.69	56	.3.18	2805	2.06	.774	.548	.708	.706	1980
6	27.	2315	14.94	68	.3.86	3220	2.41	.777	.559	.719	.694	2233
7	31.6	2795	17.69	90	.5.11	3790	2.81	.75	.553	.738	.675	2558
8	36.3	3185	19.69	110	.6.75	4360	3.09	.723	.529	.731	.682	2970
9	40.8	3545	21.31	130	.7.39	4890	3.31	.696	.505	.725	.688	3365
10	45.4	3905	22.88	146	.8.29	5450	3.70	.707	.506	.717	.697	3800



4 H.P. Wagner Induction Motor.

Volts Constant at 75.

Speed 1745

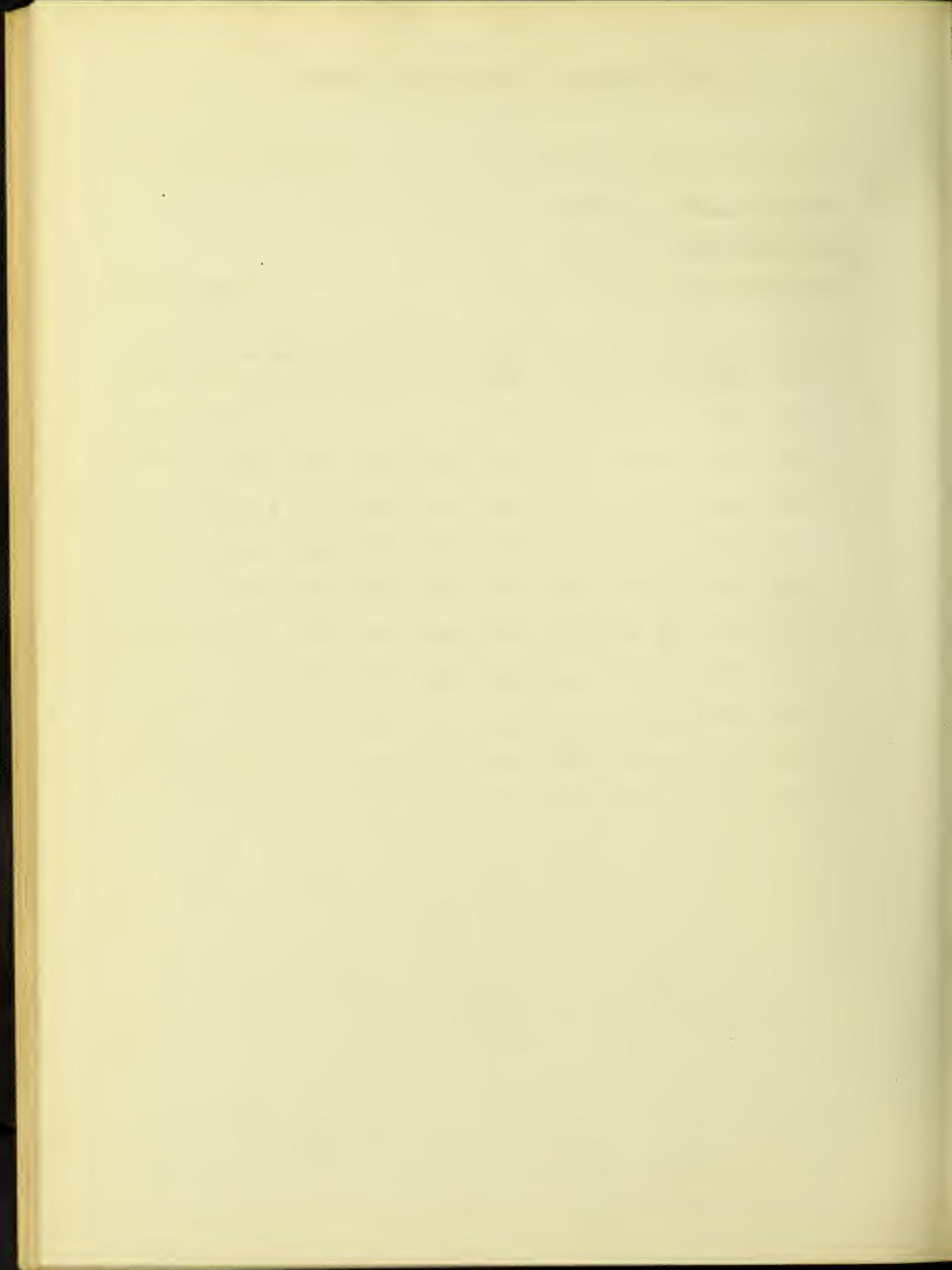
AC. Ammeter 13457

AC Voltmeter 857

AC Wattmeter 775

May 8 1900.

No	Amp	True Watts	Pull in Pounds	Slip R.P.M.	Slip %	Aph Watts	H.P.	True Eff	Aph. Eff.	Power Factor.	Induc. Factor.	Idle Watts
1	11.2	248	0	3.34	.193	840	0	0	0	.291	.957	.804
2	12.2	395	1.09	6.74	.387	914	.1805	.341	.147	.432	.902	.824
3	15.3	705	3.70	14.3	.82	1145	.61	.645	.403	.626	.780	.893
4	17.8	975	5.19	20.	1.147	1335	.851	.651	.476	.731	.682	.910
5	20.2	1155	6.57	25.	1.433	1515	1.075	.695	.529	.763	.646	.979
6	24.3	1455	8.38	33.3	1.92	1825	1.366	.701	.558	.798	.603	1100
7	27.5	1685	10.00	39.4	2.26	2065	1.62	.718	.587	.817	.577	1190
8	32.8	2055	12.13	49.6	2.84	2460	1.95	.71	.593	.835	.550	1353
9	36.6	2270	13.57	58.8	3.37	2740	2.17	.712	.593	.831	.556	1521
10	42.8	2655	14.59	73.8	4.23	3210	2.32	.652	.539	.827	.562	1804



## 4 H.P. Wagner Induction Motor

Volts Constant at 90

Speed 1745

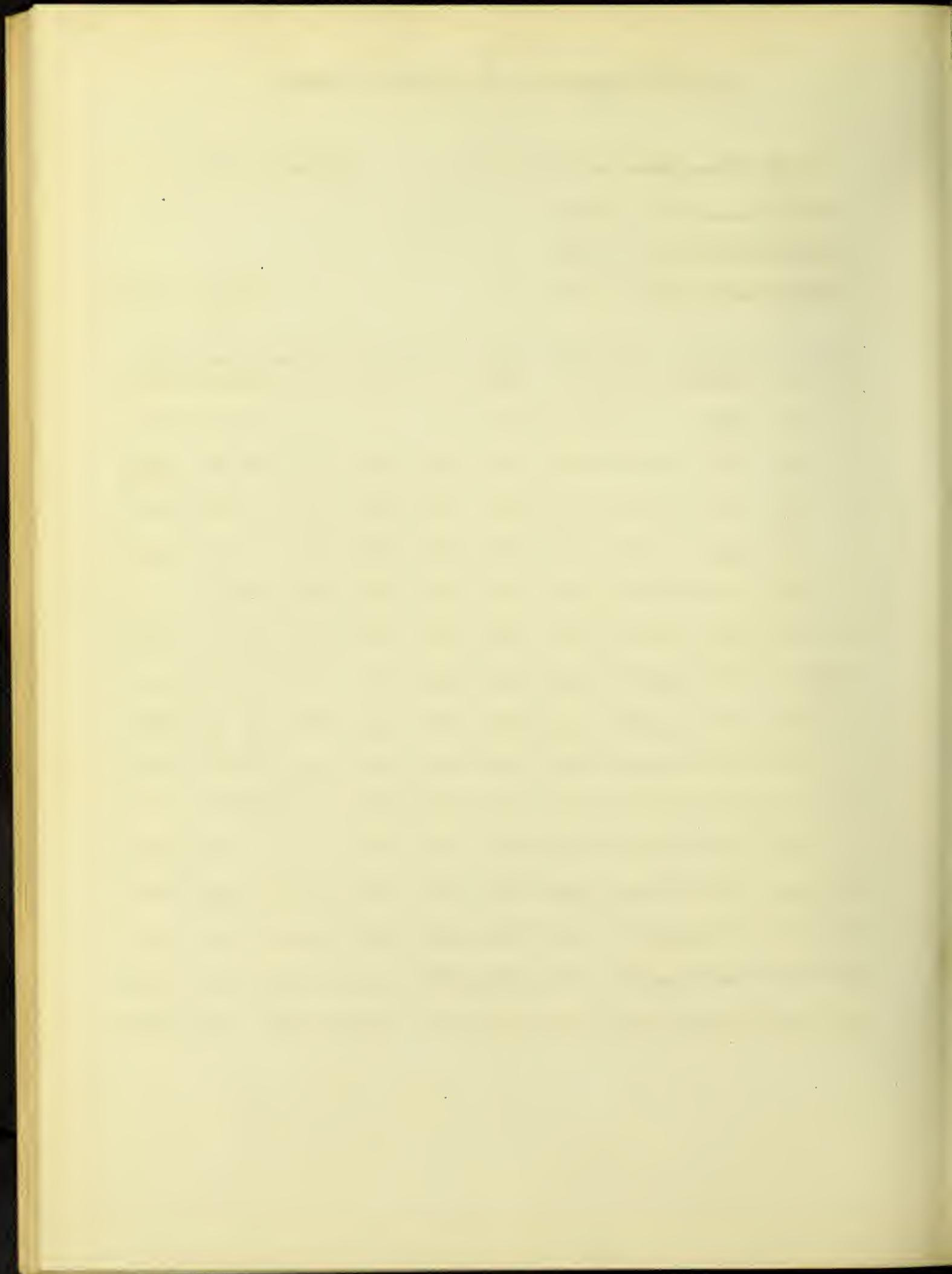
A.C. Ammeter 13457

A.C. Voltmeter 857

A.C. Wattmeter 775

May 7, 1900.

No.	Amph.	True Watts	Pull in Pounds	Slip RPM	Slip %	A.H.H. Watts	H.P.	True Eff.	A.H.H. Eff.	Power Factor	Induc. Factor	Idle Watts
1	13.6	338	0	2.26	.129	1223	0	0	0	.19	.982	1200
2	14.6	455	1.69	5.56	.39	1312	.28	.459	.159	.346	.938	1230
3	15.7	725	3.71	10.45	.599	1411	.60	.617	.317	.513	.858	1210
4	17.1	895	5.00	13.05	.748	1540	.82	.683	.398	.581	.814	1253
5	18.6	1085	6.37	16.7	.921	1672	1.04	.714	.455	.649	.761	1272
6	20.8	1295	7.81	20.2	1.15	1872	1.28	.736	.48	.691	.723	1354
7	23.7	1555	9.69	24.8	1.42	2135	1.58	.76	.552	.728	.686	1463
8	26.2	1785	11.25	28.6	1.64	2360	1.84	.77	.582	.756	.655	1545
9	28.3	2025	12.81	32.6	1.87	2575	2.09	.757	.606	.786	.618	1590
10	30.4	2185	14.06	36.4	2.09	2735	2.29	.782	.625	.798	.603	1650
11	33.5	2375	15.19	40.8	2.34	3015	2.46	.773	.608	.787	.617	1860
12	36.1	2575	16.56	46.2	2.65	3250	2.68	.775	.615	.793	.609	1980
13	39.2	2805	16.94	50.8	2.91	3525	2.74	.778	.650	.795	.607	2135
14	43.4	3015	19.40	56.6	3.24	3905	3.13	.774	.598	.772	.636	2365
15	44.4	3211	20.19	63.1	3.62	4000	3.51	.817	.655	.80	.599	2395



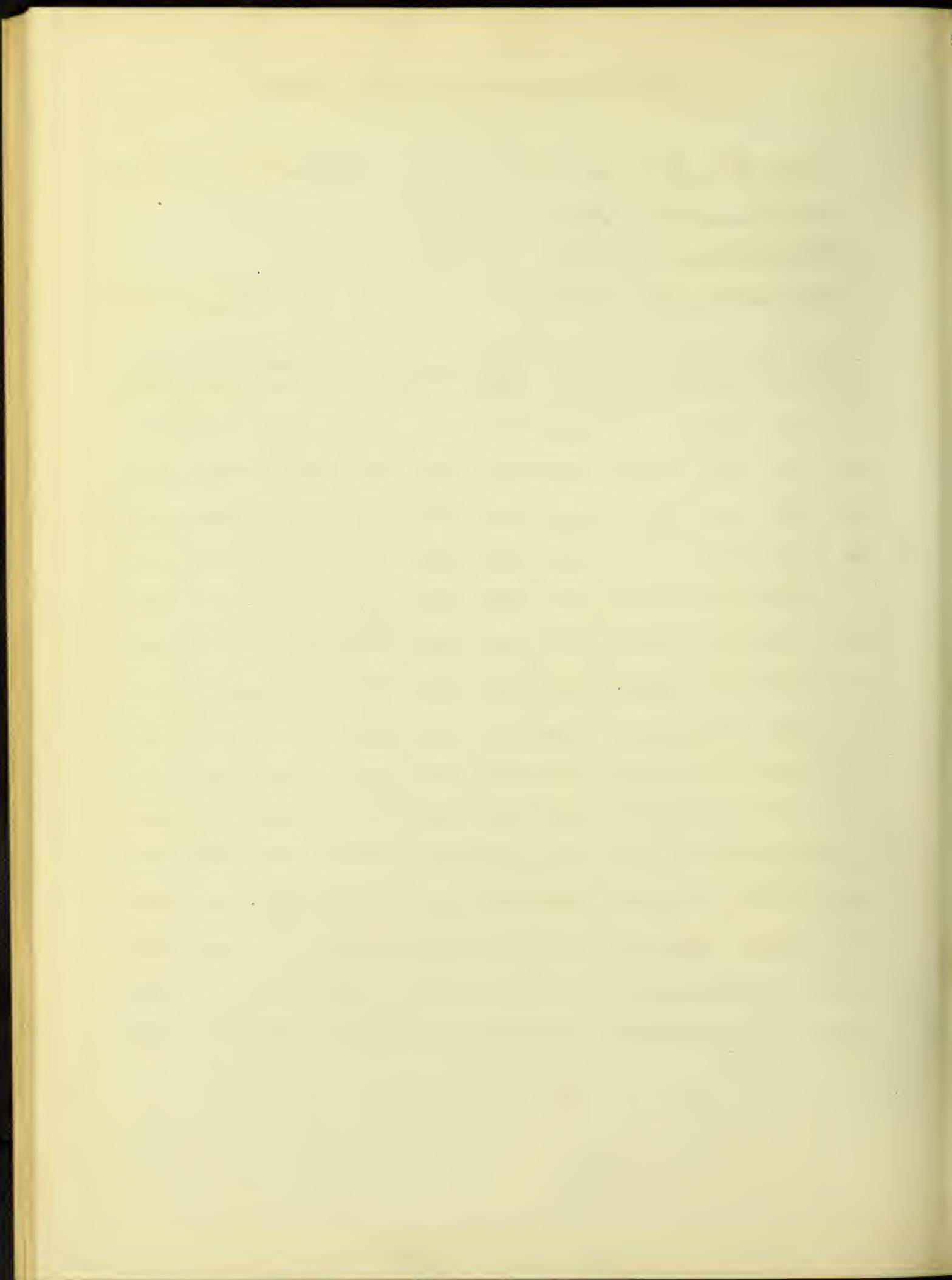
## 4 H.P. Wagner Induction Motor.

Volts Constant at 104  
 AC. Ammeter 13457  
 AC. Voltmeter 857  
 AC. Wattmeter 775

Speed 1745 R.P.M.

May 7, 1900.

No	Amh.	True Watts	Pull In hours	Slip R.P.M.	Slip %	Ahh. Watts	H.P.	True Eff	Ahh. Eff	Power Factor	Induc. Factor	Idle Watts
1	15.6	265	0	1.7	.0975	1620	0	0	0	.163	.986	1597
2	16.	395	1.37	4.05	.232	1660	.23	.435	.1031	.237	.971	1610
3	16.9	665	3.15	7.14	.409	1756	.52	.583	.2205	.378	.926	1627
4	17.7	845	4.44	9.1	.521	1840	.73	.65	.298	.459	.888	1634
5	18.7	1025	5.68	11.3	.648	1945	.93	.677	.34	.520	.853	1658
6	20.2	1245	7.69	14.3	.821	2100	1.26	.756	.448	.592	.805	1690
7	23.5	1655	10.31	19.35	1.11	2440	1.68	.758	.51	.674	.738	1800
8	26.3	1995	12.44	24	1.376	2730	2.04	.763	.557	.730	.683	1866
9	28.3	2155	13.56	27.25	1.56	2940	2.21	.767	.562	.732	.681	2005
10	30.9	2425	15.56	30.57	1.75	3210	2.50	.769	.58	.755	.655	2100
11	34.3	2705	17.69	34.75	1.99	3565	2.88	.795	.602	.758	.651	2320
12	36.7	2975	19.44	39.3	2.25	3815	3.15	.796	.633	.78	.624	2380
13	39.7	3265	21.44	44.4	2.55	4125	3.47	.795	.627	.79	.612	2527
14	42.7	3465	22.88	48.7	2.79	4440	3.69	.805	.633	.787	.616	2735
15	46.	3725	24.88	53.2	3.05	4784	4.02	.8056	.628	.780	.624	2960



4 H.P. Wagner Induction Motor

Volts Constant at 120

Speed 1745

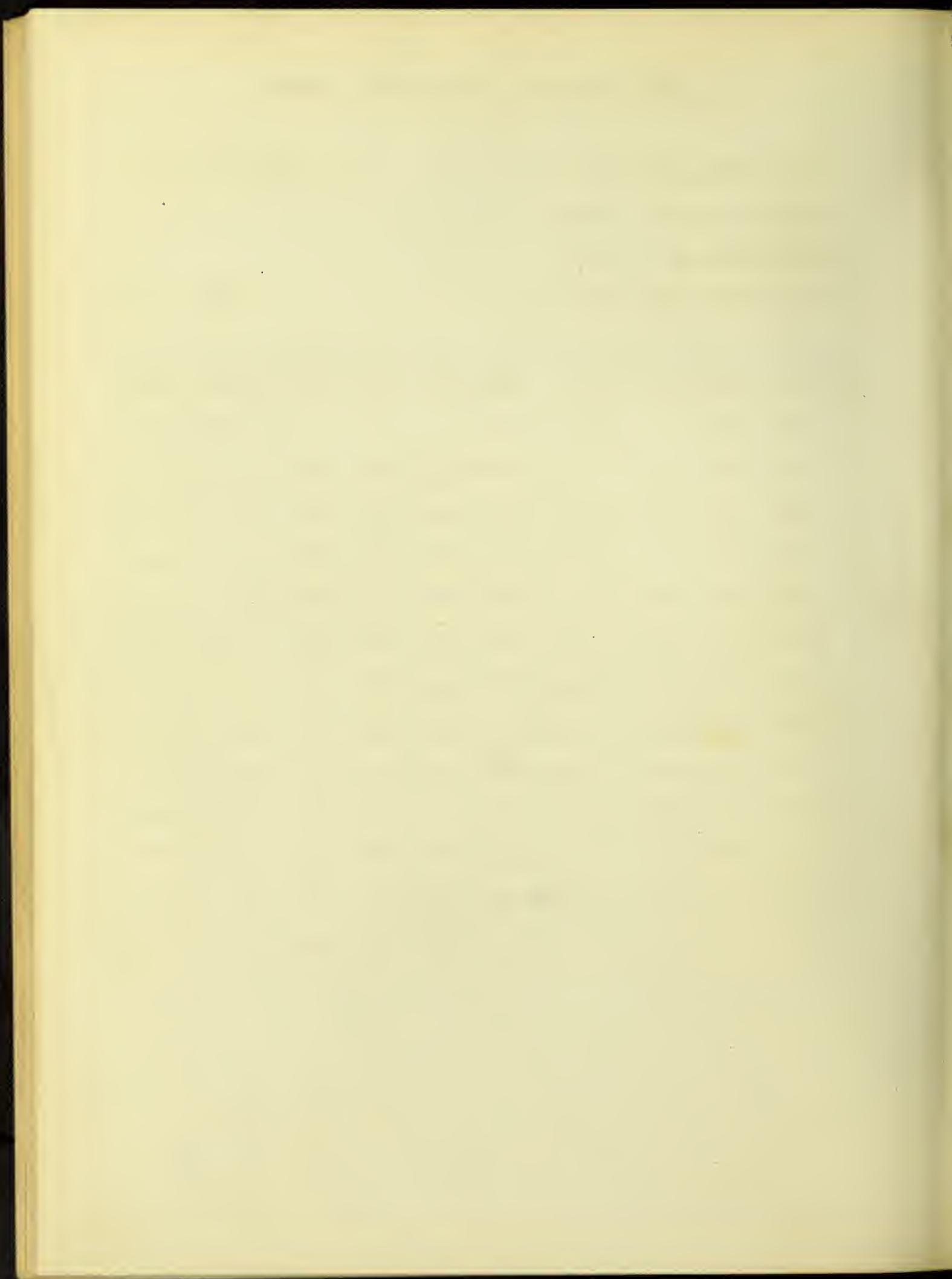
A.C. Ammeter 13457

A.C. Voltmeter 857

A.C. Wattmeter 775

May 8, 1900

No	Amp	True Watts	Pull in Pounds	Slip R.P.M.	Slip %	Amp Watts	H.P.	True Eff.	Amp Eff	Power Factor	Induc Factor	Idle Watts
1	18	355	0	158	.0906	2160	0	0	0	.1644	.986	2128
2	18.5	655	24	4.	.229	2220	.3975	.452	.133	.295	.955	2120
3	19.4	915	413	6.38	.366	2330	.682	.556	.218	.393	.919	2140
4	20.1	1105	55	8.57	.491	2415	.909	.613	.38	.457	.889	2145
5	23.	1635	9.32	13.32	.763	2760	1.535	.70	.415	.593	.805	2215
6	24.2	1835	1107	15.	.86	2905	1.820	.739	.467	.632	.775	2250
7	26.5	2155	1325	18.75	1.075	3180	2.175	.753	.511	.678	.735	2335
8	29.1	2505	15.69	22.25	1.295	3490	2.57	.766	.549	.718	.696	2425
9	31.6	2835	18.00	25.	1.433	3790	2.94	.773	.578	.748	.664	2515
10	33.5	3035	19.32	28.	1.605	4020	3.16	.776	.589	.756	.655	2630
11	35.7	3195	20.5	31.2	1.789	4280	3.28	.766	.572	.747	.665	2848
12	38.7	3515	22.69	35.9	2.059	4640	3.69	.783	.593	.757	.653	3030
13	40.3	3885	25.56	40	2.29	4835	4.14	.795	.639	.793	.609	2940



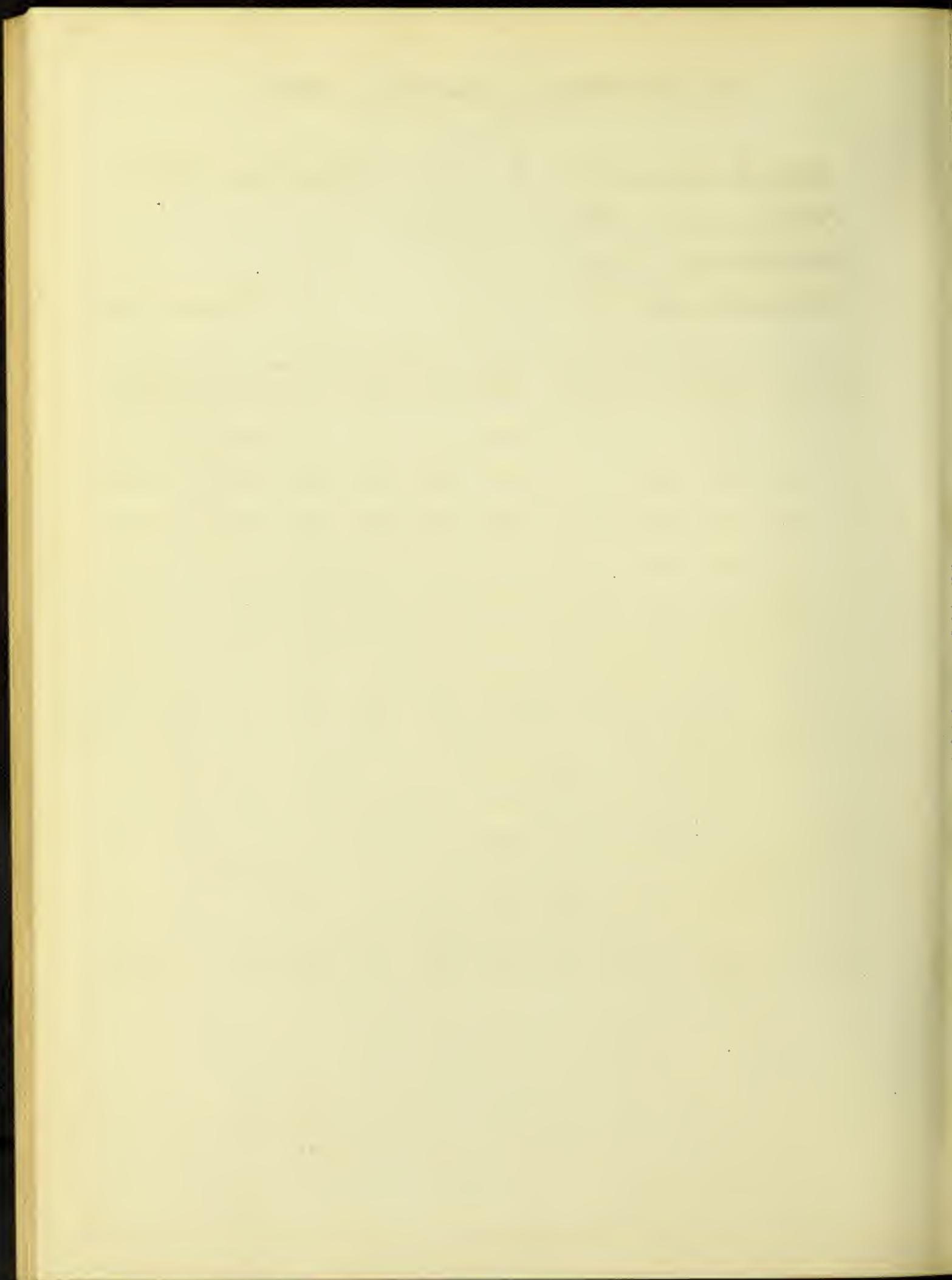
7 1/2 H.P. Wagner Induction Motor.

Volts Constant at 75  
A.C. Ammeter 13472  
A.C. Voltmeter 857  
A.C. Wattmeter 775

Speed 1745 R.P.M.

May 16, 1900.

No	Amp <sub>h</sub>	True Watts	Pull in Pounds	Slip RPM.	Slip %	Amp <sub>h</sub> Watts	H.P.	True Eff.	Amp <sub>h</sub> Eff.	Power Factor	Induc Factor	Idle Watts
1	15.9	345	0	423	24	1192	0	0	0	.389	.957	1140
2	17.3	555	164	76	44	1298	.271	.364	.156	.427	.905	1175
3	19.6	835	263	12.38	71	1469	.433	.387	.22	.568	.823	1210
4	22.8	1135	613	18.18	104	1720	1.01	.664	.438	.66	.751	1290
5	25.3	1355	756	22.25	122	1897	1.24	.682	.488	.714	.700	1325
6	27.7	1545	902	26.10	1.5	2078	1.475	.712	.53	.744	.668	1390
7	31.	1795	10.24	30.60	1.76	2330	1.67	.695	.535	.772	.636	1480
8	34.5	2095	13.01	36.15	2.07	2588	2.12	.755	.611	.81	.587	1520
9	37.5	2295	13.50	40.6	2.32	2810	2.19	.712	.581	.818	.574	1610
10	40.6	2495	15.88	44.4	2.54	3045	2.54	.768	.63	.82	.572	1740
11	42.9	2655	17.00	50.0	2.86	3220	2.74	.77	.634	.825	.564	1815
12	46.9	2965	18.94	56.1	3.21	3515	3.04	.766	.646	.844	.536	1885
13	51.3	3225	20.63	63.2	3.62	3850	3.3	.763	.639	.838	.544	2095



7 1/2 H.P. Wagner Induction Motor.

Volts Constant at 90.

Speed 1761 R.P.M.

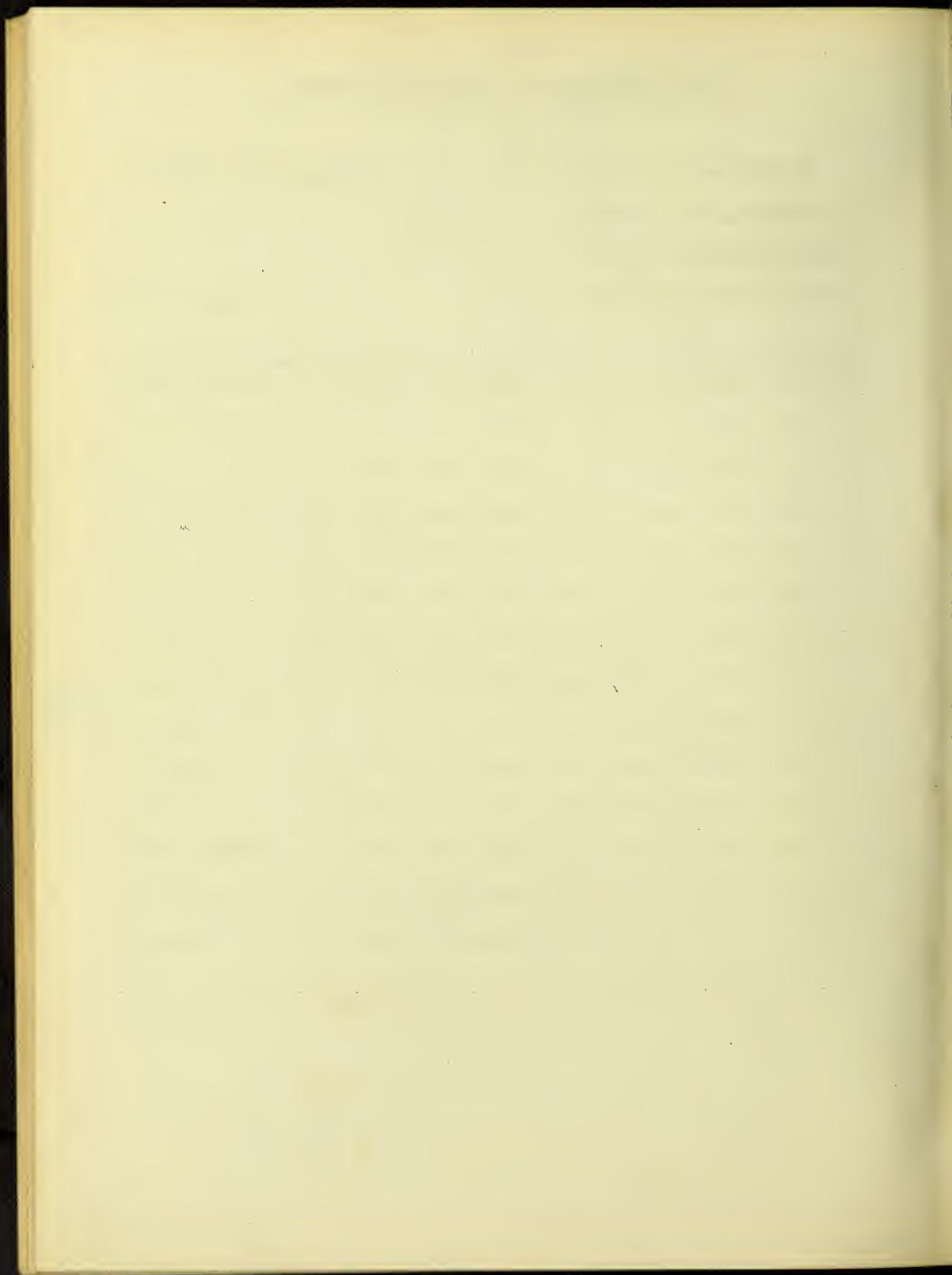
A.C. Ammeter 13457

A.C. Voltmeter 857

A.C. Wattmeter 775

May 21, 1900.

No.	Amp.	True Watts	Pull in pounds	Slip R.P.M.	Slip %	Aph. Watts	H.P.	True Eff.	Aph. Eff.	Power Factor	Induc. Factor	Idle Watts
1	19.4	435	0	3.16	.17	1746	0	0	0	.2525	.9675	1689
2	23	1075	5.19	10.7	.60	2065	.863	.599	.312	.5210	.8535	1716
3	25.6	1415	7.64	15.	.85	2304	1.26	.634	.325	.6145	.7889	1820
4	30.9	2015	11.96	22.2	1.26	2780	1.79	.658	.493	.7255	.6881	1910
5	34.9	2435	14.96	27	1.55	3140	2.46	.755	.585	.7760	.6307	1978
6	38.	2685	16.77	30.9	1.75	3420	2.76	.767	.603	.7860	.6182	2115
7	42.6	3115	19.70	37.	2.10	3835	3.23	.775	.628	.8130	.5821	2230
8	46.4	3465	22.21	41.6	2.36	4170	3.63	.781	.650	.8310	.5563	2320
9	52.	3905	25.25	49.2	2.60	4680	4.12	.788	.657	.8350	.5502	2573
10	59.	4325	28.25	56.6	3.21	5310	4.42	.763	.621	.8145	.5800	3078
11	65.5	4725	31.37	62.5	3.55	5890	4.89	.772	.62	.8030	.5960	3513
12	71.8	5075	33.13	69.	3.92	6460	5.28	.777	.611	.7865	.6175	3850
13	80.	5775	36.44	78.	4.42	7200	5.78	.746	.599	.8030	.5960	4285



7 1/2 H.P. Wagner Induction Motor.

Volts Constant at 104.

Speed 1745 R.P.M.

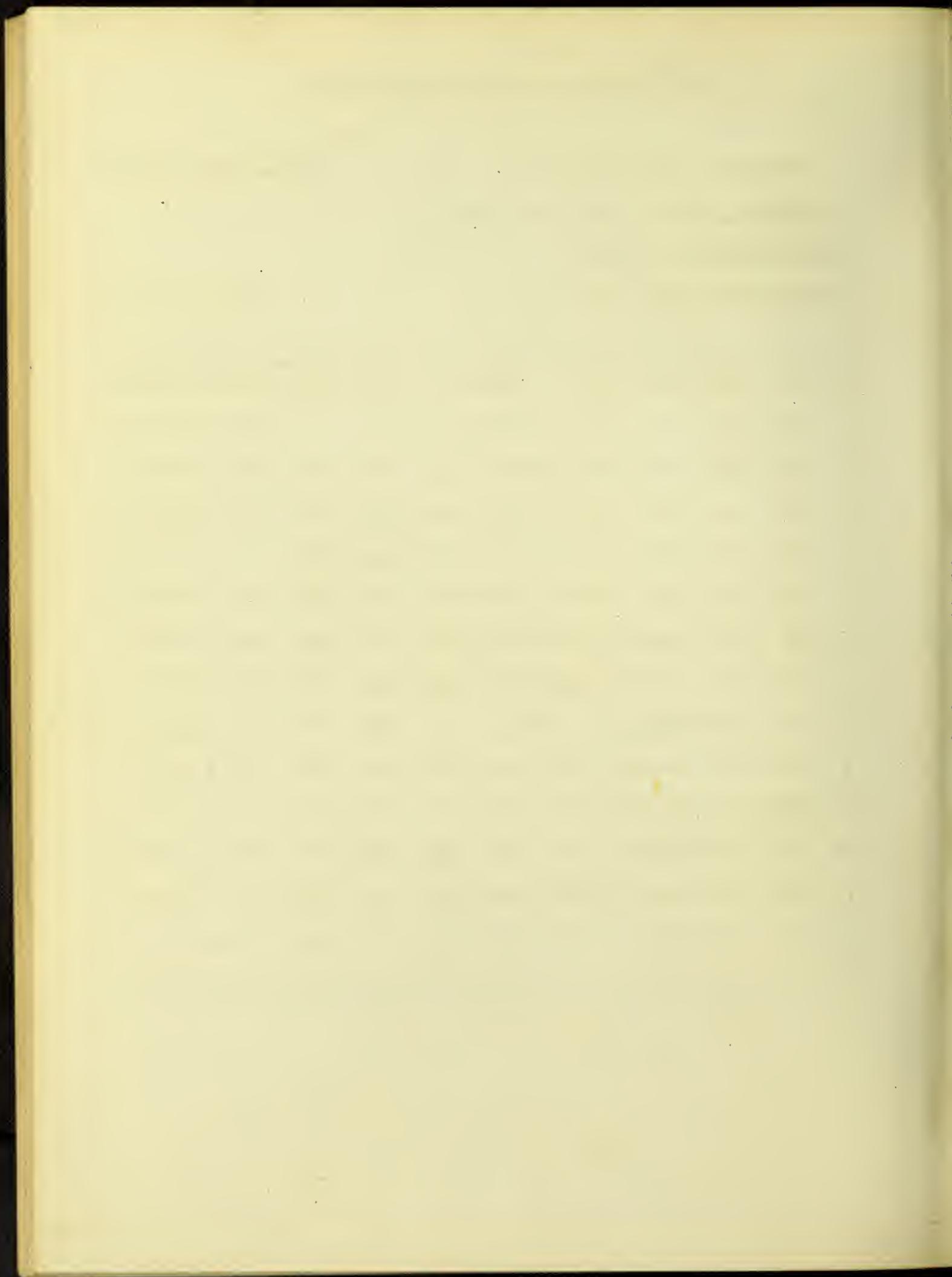
AC. Ammeter 13454 + 13472.

AC. Voltmeter 831

AC. Wattmeter 775

May 10, 1900.

No	Amt	True Watts	Pull in Pounds	Slip RPM	Slip %	Amt Watts	H.P.	True Eff.	Amt Eff.	Power Factor	Induc. Factor	Idle Watts
1	22.8	515	0	3	.172	2370	0	0	0	.2385	.971	2300
2	26.6	1355	563	10.35	.594	2770	.93	.512	.25	.489	.872	2415
3	28	1635	776	12.5	.717	2910	1.28	.584	.328	.556	.831	2420
4	30.1	1915	988	14.63	.84	3115	1.63	.635	.39	.615	.788	2455
5	32.5	2185	1219	17.65	1.01	3380	2.01	.688	.444	.647	.762	2575
6	35	2525	1465	20.7	1.185	3640	2.41	.713	.494	.694	.719	2615
7	37.5	2815	1663	23.6	1.35	3900	2.73	.724	.522	.722	.692	2700
8	40.2	3145	1894	27.3	1.565	4180	3.10	.736	.553	.752	.659	2755
9	43.6	3515	2169	30.	1.72	4540	3.54	.751	.581	.775	.632	2870
10	46.2	4015	2825	35.3	2.02	4810	4.60	.855	.714	.835	.550	2645
11	49.2	4365	2875	37.5	2.15	5120	4.67	.798	.681	.853	.522	2670
12	53.8	4755	3145	41.65	2.39	5600	5.10	.801	.679	.85	.526	2945
13	57	5175	3430	44.4	2.54	5930	5.55	.800	.698	.873	.488	2895
14	60	5445	3640	49.15	2.82	6250	5.88	.807	.703	.871	.491	3070



## 7½ H.P. Wagner Induction Motor.

Volts Constant at 120.

Speed 1795

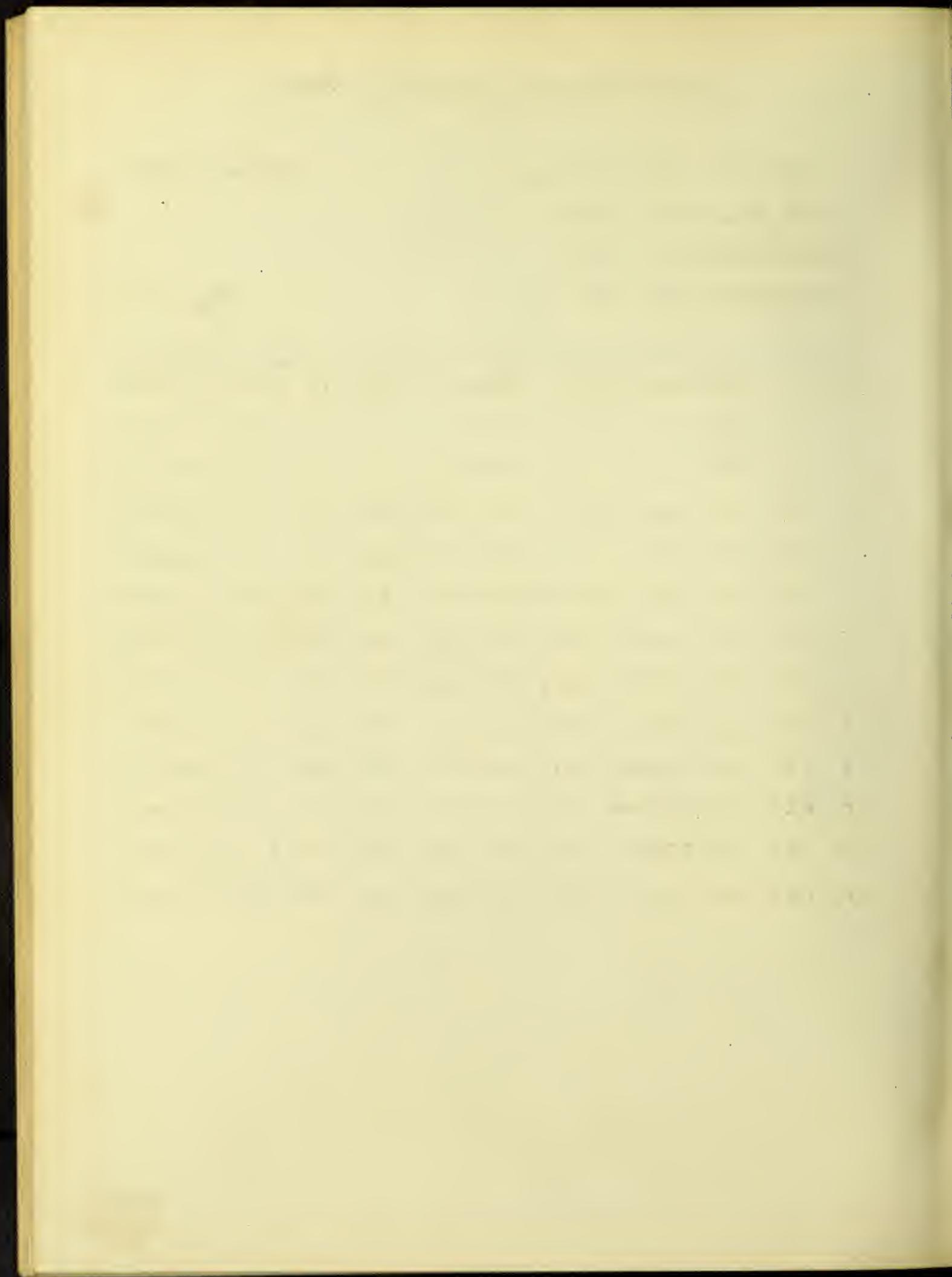
A.C. Ammeter 13472

A.C. Voltmeter 857

A.C. Wattmeter 775

May 23, 1900

No.	Amp <sub>h</sub>	True Watts. cold	Pull in Pounds.	Slip RPM.	Slip %	Aph Watts	H.P.	True Eff.	Aph Eff.	Power Factor	Induc. Factor	Idle Watts
1	27.4	620	0	2.28	.0787	3285	0	0	0	.189	.982	3225
2	27.1	525	0	2.	.111	3250	0	0	0	.162	.987	3210
3	28.	1055	4.44	5.88	.305	3360	756	.535	.168	.314	.949	3190
4	30.3	1635	8.94	10.	.557	3635	1.52	.693	.312	.45	.893	3245
5	36.4	2775	17.44	18.75	1.044	4365	2.87	.772	.49	.636	.772	3370
6	42.	3585	23.54	25.	1.39	5040	3.97	.826	.588	.712	.701	3530
7	46.	4155	27.60	30.	1.67	5520	4.65	.835	.629	.754	.656	3620
8	50.	4745	31.62	33.3	1.86	6000	5.30	.834	.66	.791	.612	3670
9	55.3	5335	35.94	38.7	2.16	6640	6.00	.839	.674	.804	.594	3945
10	58.5	5715	38.32	40.	2.23	7015	6.40	.835	.68	.816	.577	4050
11	59.2	5815	38.98	41.1	2.29	7100	6.50	.834	.683	.82	.573	4070
12	63.2	6245	41.67	43.8	2.44	7580	6.95	.831	.684	.824	.566	4280



## 10 H.P. Wagner Induction Motor

Volts Constant at 208.

A.C. Ammeter 13472

A.C. Voltmeter 857

A.C. Wattmeter 775

May 18, St. Louis

No	Volts	Amp	Watts	Speed	Slip	Amp Watts	H.P.	True Eff.	Amp Eff.	Power Factor	Induc Factor	Idle Watts.
1	207.8	11.7	525	1815		2430	0	0	0	.216	.976	2370
2	207.2	16.9	2585	1800		3500	2.5	.722	.533	.739	.673	2355
3	208.2	26.2	4555	1785		5460	5.	.819	.683	.835	.549	3000
4	207.8	37.9	6740	1760		7880	7.5	.830	.710	.855	.518	4080
5	206	55.	9125	1740		11320	10	.819	.659	.856	.517	5850
6	210.4	75.	13425	1685		15790	12.1	.672	.572	.851	.525	8290

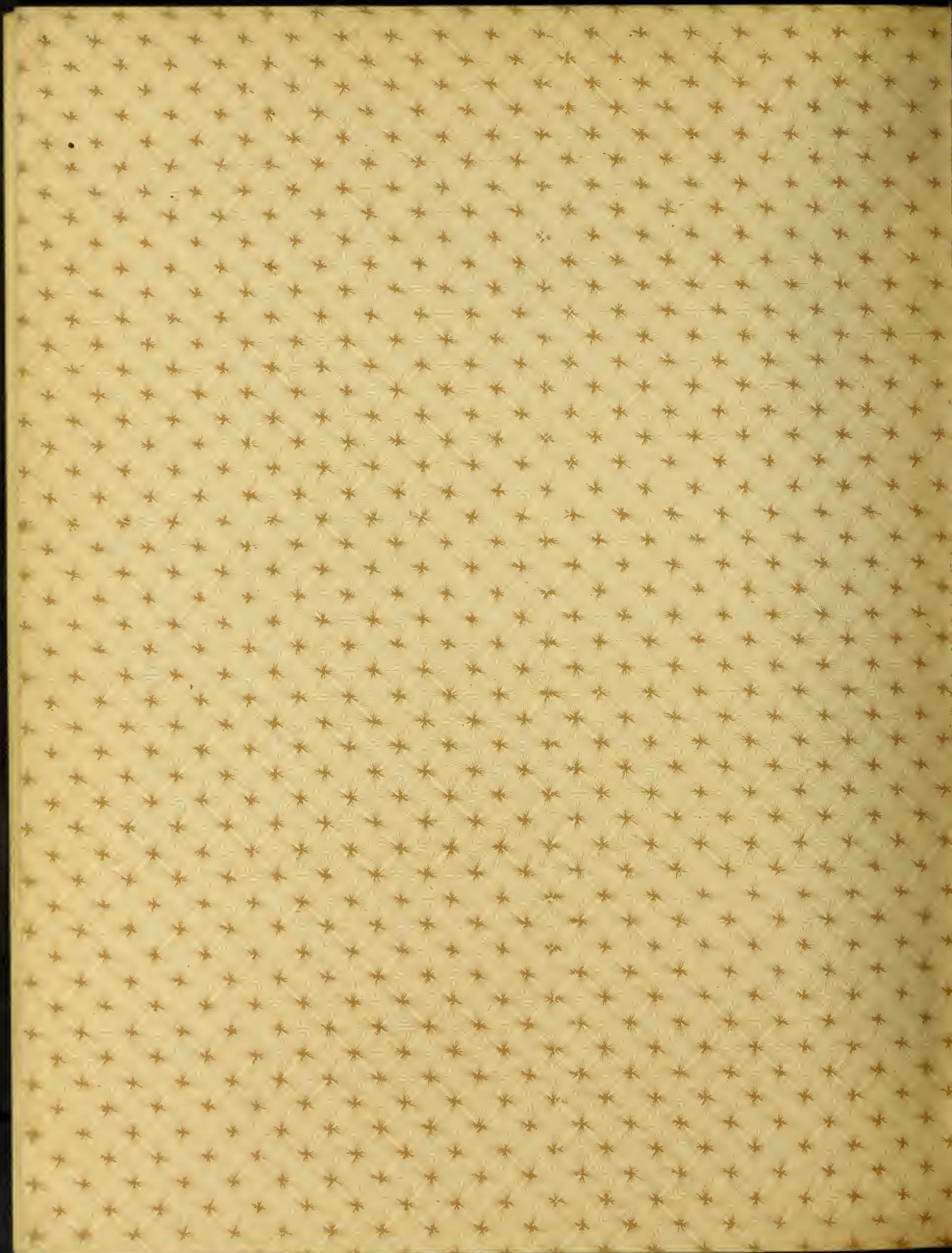


Comparison of Instruments.

Readings taken during factory test

of 10 H.P. Motor.

% LOAD	Voltmeters		Ammeters		Wattmeters		Speed R.P.M.
	Wagner	V of I	Wagner	V of I	Wagner	V of I	
0	103.0	103.9	11.7	11.4	550	550	1815
25	103	103.6	16.2	16.5	2410	2610	1800
50	103.5	104.1	25.5	25.5	4770	4580	1785
75	103.25	103.9	35.5	37.	7150	6765	1760
100	102.5	103.	50.7	53.6	9350	9150	1740
120	104.75	105.2	77.	79.	13100	1345.	1685





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